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SPACE, TELECOMMUNICATIONS AND RADIOSCIENCE LABORATORY

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# LONG-TERM AVERAGES OF GLOBALLY-MEASURED ELF/VLF RADIO NOISE



by

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Technical Report E450-2

March 1992



Sponsored by
The Office of Naval Research
through
Contract No. N00014-81-K-0382 and Grant No. N00014-90-J-1080

# REPORT DOCUMENTATION PAGE

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|---|---|
| 1. REPORT NUMBER: E 450-2 | 2. GOVT ACCESSION NO. |
| 3. RECIPIENT'S CATALOG NUMBER | |
| 4. TITLE (and Subtitle): LONG-TERM AVERAGES OF GLOBALLY-MEASURED ELF/VLF RADIO NOISE | 5. TYPE OF REPORT & PERIOD COVERED: TECHNICAL |
| | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s): M.M. BOWEN, A.C. FRASER-SMITH, P.R. MCGILL | 8. CONTRACT OR GRANT NUMBER(s): CONTRACT No. N00014-81-K-0382 GRANT No. N00014-90-J-1080 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS: SPACE, TELECOMMUNICATION, AND RADIOSCIENCE LAB. DURAND BUILDING, STANFORD UNIVERSITY STANFORD, CA 94305-4090 | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR089-171 and R&T No. 4149171 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS: OFFICE OF NAVAL RESEARCH, CODE 1114SP 800 QUINCY STREET ARLINGTON, VA 22217 | 12. REPORT DATE: MARCH, 1992 |
| | 13. NUMBER OF PAGES: 48 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | 15. SECURITY CLASS. (of this report): UNCLASSIFIED |
| | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

DISTRIBUTION UNLIMITED, APPROVED FOR PUBLIC RELEASE AND SALE.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

ELF NOISE  VLF NOISE  GLOBAL NOISE MEASUREMENTS
LONG-TERM NOISE MEASUREMENTS  SFERICS  CHORUS  HISS
RADIO NOISE STATISTICS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

IN THIS REPORT WE PRESENT THE RESULTS OF A STATISTICAL STUDY OF A YEAR OF DATA OBTAINED AS PART OF THE STAR LABORATORY'S GLOBAL SURVEY OF ELF/VLF RADIO NOISE (FREQUENCIES IN THE RANGE 10 HZ TO 32 kHZ). THE DATA INCLUDED IN THE STUDY WERE OBTAINED DURING THE ONE-YEAR PERIOD DECEMBER 1986 THROUGH NOVEMBER 1987 FROM SEVEN MEASUREMENT INSTRUMENTS ("RADIOMETERS") LOCATED AT BOTH HIGH AND LOW LATITUDES. AVERAGE AMPLITUDES AND VOLTAGE DEVIATION ($V_d$) STATISTICS FROM EACH OF THE SEVEN STATIONS WERE FIRST DIVIDED INTO FOUR THREE-MONTH

BLOCK 20 CONT.

SEASONS AND THEN AVERAGED AT EVERY MEASUREMENT FREQUENCY IN TWO SEPARATE LONG-TERM AVERAGES.

THE FIRST LONG-TERM AVERAGE INVOLVED FURTHER DIVIDING THE MEASUREMENTS INTO THE SIX FOUR-HOUR TIME BLOCKS IN A DAY AND AVERAGING WITHIN THESE HOURLY BLOCKS ACROSS AN ENTIRE SEASON (E.G., ALL MEASUREMENTS MADE BETWEEN 0000 TO 0400 UT FOR A SEASON WERE AVERAGED TOGETHER). THIS PROCESS RESULTED IN A SET OF SIX SPECTRAL DISTRIBUTIONS FOR EACH SEASON. THUS, THE AVERAGES EMPHASIZE DIURNAL TRENDS IN THE NOISE AMPLITUDES AND $V_d$ VALUES. THE SECOND LONG-TERM AVERAGE WAS OBTAINED BY AVERAGING ALL THE MEASUREMENTS TAKEN DURING A SEASON AND THUS OBTAINING ONE SPECTRAL DISTRIBUTION FOR EACH SEASON. THIS LONG-TERM AVERAGE SHOWS SEASONAL FEATURES IN THE NOISE AMPLITUDES AND $V_d$ VALUES.

BOTH SETS OF LONG-TERM AVERAGES SHOW CHARACTERISTIC TRENDS IN THE MEASUREMENTS DUE TO THE MANNER IN WHICH NOISE PROPAGATES IN THE EARTH-IONOSPHERE WAVEGUIDE. THE AVERAGE AMPLITUDES OF THE MEASUREMENTS DECREASE WITH FREQUENCY, REACHING A MINIMUM AROUND 1 kHZ, AND RISE AGAIN TOWARDS 10 kHZ. THE $V_d$ AMPLITUDES GENERALLY RISE WITH FREQUENCY EXCEPT FOR A DEPRESSION OF VALUES AROUND 1 kHZ.

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# ABSTRACT

In this report we present the results of a statistical study of a year of data obtained as part of the STAR Laboratory's global survey of ELF/VLF radio noise (frequencies in the range 10 Hz to 32 kHz). The data included in the study were obtained during the one-year period December 1986 through November 1987 from seven measurement instruments ("radiometers") located at both high and low latitudes. Average amplitude and voltage deviation ($V_d$) statistics from each of the six stations were first divided into four three-month seasons and then averaged at every measurement frequency to give two separate sets of long-term averages.

The first set of averages was obtained by further dividing the measurements into the six 4-hour time blocks in a day and averaging within these hourly blocks across an entire season (e.g., all measurements made between 0000 to 0400 UT for a season were averaged together). This process resulted in a set of six spectral distributions for each season. Thus, the averages emphasize diurnal trends in the noise amplitudes and $V_d$ values. The second set of long-term average was obtained by averaging all measurements taken during a season and thus obtaining one spectral distribution for each season. This long-term average shows seasonal features in the noise amplitude and $V_d$ values.

Both sets of long-term averages show characteristic trends in the measurements due to the manner in which noise propagates in the earth-ionosphere waveguide. The average amplitudes of the measurements decrease with frequency, reaching a minimum around 1 kHz, and rise again towards 10 kHz. The $V_d$ amplitudes generally rise with frequency except for a depression of values around 1 kHz.

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# 1. INTRODUCTION

As we have previously reported [1, 2, 3] our laboratory is presently conducting a global survey of extremely-low frequency (ELF; 5 Hz–3 kHz) and very-low frequency (VLF; 3 kHz–30 kHz) radio noise covering frequencies in the range 10 Hz–32 Hz. Noise statistics at all eight measurement locations are dominated by lightning-generated noises (predominantly sferics). Data from our three high latitude radiometers (Thule (TH; 76.5 N, 68.8 W) and Søndrestrømfjord (SS; 67.0° N, 50.1° W) in Greenland, and Arrival Heights (AH; 77.8° S, 193.3° W) in the Antarctic) include samples of polar hiss and greater amounts of other ELF/VLF radio noise of magnetospheric origin, such as chorus, than measurements made at our five lower latitude radiometers (Grafton, New Hampshire (43.6° N, 72.0° W); L'Aquila, Italy (43.4° N, 13.3° E); Stanford, California (37.4° N, 122.2° W); Kochi, Japan (33.3° N, 226.5° W); and Dunedin, New Zealand (45.8° S, 189.5° W)). A map showing the geographical locations of these stations is given in Figure 1.

The radio noise statistics computed continuously at each of the stations consist of the average, root-mean-square (rms), maximum, and minimum amplitudes in 16 narrow frequency bands (5% bandwidth) distributed over the ELF and VLF ranges (Table 1). They are computed at the end of every minute from 600 amplitude measurements made at the rate of 10 per second on the envelope of the noise signal emerging from each narrow-band filter (during calibration the number of measurements is reduced but never to less than 400 measurements/minute). In addition to these recordings, synoptic broadband ELF digital recordings are made for one minute every thirty minutes and synoptic broadband VLF analog recordings are made for one minute every hour. Processing of the narrow-band digital data can, with little additional computation, give the voltage deviation ($V_d$), effective antenna noise factor ($F_a$), and amplitude probability distributions (APD's). These various statistical quantities are widely used to characterize radio noise, and they are described in several reports issued by the International Radio Consultative Committee, or CCIR [4, 5]. Although we have made comparisons at 32 kHz between our noise data and the $F_a$ statistics presented in the CCIR reports [6], we are unable to make comparisons at all frequencies because 14 of our 16 measurement frequencies are below the 10 kHz minimum frequency for the CCIR statistics.

TABLE 1. Center frequencies and bandwidths for the 16 channels of the ELF/VLF noise measurement systems.

| Channel | Center Frequency | Bandwidth (5%) |
|---|---|---|
| 1 | 10 Hz | 0.5 Hz |
| 2 | 30 | 1.5 |
| 3 | 80 | 4 |
| 4 | 135 | 6.75 |
| 5 | 275 | 13.75 |
| 6 | 380 | 19 |
| 7 | 500 | 25 |
| 8 | 750 Hz | 37.5 |
| 9 | 1 kHz | 50 |
| 10 | 1.5 | 75 |
| 11 | 2 | 100 |
| 12 | 3 | 150 |
| 13 | 4 | 200 |
| 14 | 8 | 400 |
| 15 | 10.2 | 510 |
| 16 | 32 kHz | 1600 Hz |

## 2. AMPLITUDE MEASUREMENTS

### 2.1. Data Analysis

The one-minute average data obtained from the stations can be processed in many different ways to give additional information about the morphology of ELF/VLF noise [7, 8]. One important form of processing we use is the computation of average amplitudes over long time intervals, such as three months. The upper panel of Figure 2 shows a three-month average using data collected at Kochi, Japan (our station of lowest geographic latitude) during winter (December, January, February). Each day was divided into six periods of four hours and the one-minute average amplitudes were averaged together according to the time of day in which they were measured. (For example, all measurements taken between 0000 to 0400 Universal Time (UT) were averaged to obtain one value at each measurement frequency.) The result is the set of six spectral distributions that provide information about the diurnal variation of the ELF/VLF noise spectrum at Kochi during the winter of 1986. Figures 2-3 are similar plots showing the variations at Kochi in spring (March, April, May), summer (June, July, August) and autumn (September, October, November) of 1987. Graphs derived in an identical manner are presented in Figures 4-15 for the same 1986-1987 seasons at six other stations arranged in order of increasing geographic latitude: Stanford, L'Aquila, Dunedin, Søndrestrømfjord, Thule, and Arrival Heights. Although two of our stations are in the southern hemisphere we have used the northern hemisphere season names when referring to specific three-month periods in an effort to retain consistency in our nomenclature. Thus, we have used the season 'winter' to describe the months December, January, and February regardless of the hemisphere in which the station is located.

One-minute amplitude measurements were also averaged for each three-month season in the 1986-1987 year at each of the sixteen measurement frequencies in order to define any seasonal trends in the ELF/VLF noise. The results obtained for each station during the four seasons between December 1986 and November 1987 are shown in Figures 16-19.

## 2.2. Discussion

The ELF noise amplitudes measured at Thule and L'Aquila below 135 Hz are consistently an order of magnitude greater than those from other stations. Although Thule is considerably closer to a geomagnetic pole than any of our other stations [9], there is no reason to expect higher ELF noise amplitudes near a geomagnetic pole and there is no previous record of such measurements. At this time we tentatively ascribe the high amplitudes to broad band ELF interference from the nearby air base. The higher ELF noise amplitudes at L'Aquila are almost certainly due to interference from the Italian electric railroad system [10].

The amount of usable data collected by the radiometer at Thule is reduced to half by the operation of the nearby Thule Ionosonde. The ionosonde operates in two-hour periods every other two-hour period (0000–0200 UT, 0400–0600 UT,..., 2000–2200 UT). Although the primary frequencies produced by the ionosonde range from 10 to 30 kHz, we see contamination at all our measurement frequencies during its periods of operation and thus exclude from our statistical studies all measurements made during these periods.

The measurements made at 32 kHz by the radiometer at Stanford University during the year of data used in this study have been found to be contaminated by a narrowband signal or modulation product at ~31.5 kHz that appears to be man-made in origin. An examination of our broadband recordings has showed that this signal occurring sporadically with different strengths at different times throughout the 1986–1987 year.

The 10.2 kHz measurement channel of the radiometers coincides with one of the broadcast frequencies of the globally-located Omega navigation stations. As a result, the data from this channel are occasionally contaminated with the navigation signals. The extent of this contamination depends on the location of the radiometer with respect to the Omega stations and the propagation characteristics of the path between them. The signals are readily identified by examining one-minute synoptic VLF broadband recordings that are made automatically by each radiometer every hour.

The graphs cf average noise amplitudes from each station show many of the same general trends. All exhibit a ~1/f decrease of amplitude with frequency culminating in a depression of amplitudes around 1 kHz. At higher frequencies the amplitudes rise again, creating an elevation of amplitudes around 10 kHz. Much of this general morphology can be attributed to the characteristics of the earth-ionosphere waveguide. At ELF frequencies only the transverse electromagnetic (TEM) waves can propagate through the guide. As the frequency increases the attenuation of TEM waves in the earth-ionosphere waveguide also increases reducing the amplitude of noise measured at higher frequencies. Around 1–3 kHz the first-order modes of quasi-transverse electric (QTE) and quasi-transverse magnetic (QTM) waves can propagate. As the frequency increases, higher order QTE and QTM modes contribute to the propagation of noise [11]. Thus, the levels of noise begin to increase around 1–3 kHz when the QTE and QTM modes begin to contribute to noise propagation.

# 3. $V_d$ MEASUREMENTS

## 3.1. Data Analysis

We processed seasonal averages of the one-minute $V_d$ measurements for each of the six stations in a manner identical to the average amplitude measurement processing. One-minute averages of the $V_d$ measurements were averaged over a three-month season for each of the six four-hour time divisions of a twenty-four-hour UT day at each of the sixteen measurement frequencies. Figures 20–33 show the results using all available data from December 1986 to November 1987 for the seven stations, Kochi, Stanford, L'Aquila, Dunedin, Søndrestrømfjord, Thule, and Arrival Heights.

The seasonal variations may be examined by averaging the one-minute $V_d$ measurements in each three-month season and comparing the seasons over an entire year. Figures 34–37 are the seasonal averages for the six stations from December 1986 to November 1987.

## 3.2. Discussion

$V_d$ is a measure of the 'spikiness' of noise data and is computed by taking the ratio (in dB) of the rms amplitude to the average amplitude. For example, noise with Gaussian distributions of both amplitude and phase is characterized by a Rayleigh distribution and has a $V_d$ of 1.05 dB [12]. Distributions containing a greater percentage of measurements at very high amplitudes have greater $V_d$ amplitudes. Natural ELF/VLF noise contains sferics, or lightning-generated bursts of energy, that can have high amplitudes and thus, depending on the amount of lightning activity, can give values of $V_d$ considerably higher than a Rayleigh distribution. Most of the $V_d$ values measured at our stations lie in the range 1-10 dB. However, a sharp minimum occurs near 1 kHz at almost every station. The values of $V_d$ in this minimum are often below those typical of a Rayleigh distribution, and they sometimes drop as low as 0.1 dB, as shown in the lower panel of Figure 35. Low values of $V_d$ are known to occur when measurements are made of a sinusoidal signal within atmospheric noise. An increase in the signal-to-noise ratio results in a decrease in $V_d$ [12]. We believe the reduction of natural noise around 1 kHz, due to the earth-ionosphere waveguide cutoff, allows the detection of very weak coherent signals, such as local man-made noise, that are normally below the level of natural activity. Apart from the depression of $V_d$ around 1–3 kHz, the values of $V_d$ tend to increase with increasing frequency indicating that noise becomes more impulsive at higher frequencies.

## 4. CONCLUSION

We have presented long-term statistics of average amplitude and $V_d$ statistics from our global array of ELF/VLF radio noise measurement systems. Data from six stations were individually averaged over a one year period from December 1986 to November 1987. The data were first averaged in periods of four hours over a three-month interval in order to show diurnal variations within a season. The data were also averaged across an entire three-month period in order to show seasonal variations during the year-long measurement period.

The long-term averages of average amplitude and $V_d$ presented here show the effects of the earth-ionosphere waveguide on the propagation of radio noise. For example, the height and conductivity of the ionosphere determine the rate at which the TEM wave attenuates with frequency and the frequency at which higher modes begin to propagate. These effects are apparent in our data. The noise amplitudes tend to decrease with increasing frequency due to increased attenuation of the TEM wave. At 1–3 kHz and above, the QTE and QTM waves begin to propagate and the noise amplitudes increase. The $V_d$ values tend to increase with increasing frequency indicating greater 'spikiness' in the noise. The prominent minimum of $V_d$ values around 1 kHz is probably due to the reduction of natural noise levels allowing the measurement of local weak coherent signals.

## AKNOWLEDGEMENTS

This research was sponsered by the Office of Naval Research through Contract No. N00014-81-K-0382 and Grant No. N00014-90-J-1080. Support for the measurements at Thule, Greenland, was provided by Rome Air Development Center through Contract No. F10629-84-0043. Important logistics support for the measurements at Søndrestrømfjord, Greenland, and Arrival Heights, Antarctica, was provided by the National Science Foundation (NSF) through NSF cooperative agreement ATM 88-22560 and NSF Grant DPP-8720167, respectively. We thank Tom Afferton and Paul R. McGill of our laboratory for their assistance with the data; Professors T. Ogawa and M. Kusunose of Kochi University for their cooperation in the measurements in Japan; Mr. J. T. Turtle of Rome Air Development Center for his cooperation in the Thule measurements; Dr. Neil R. Thomson of the University of Otago for his cooperation in the New Zealand measurements; Drs A. Meloni and P. Palangio of the Istituto Nazionale di Geofisica for their cooperation in the Italian measurements, and Dr. J. D. Kelly of SRI International for facilitating the measurements at Søndrestrømfjord.

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FIGURES

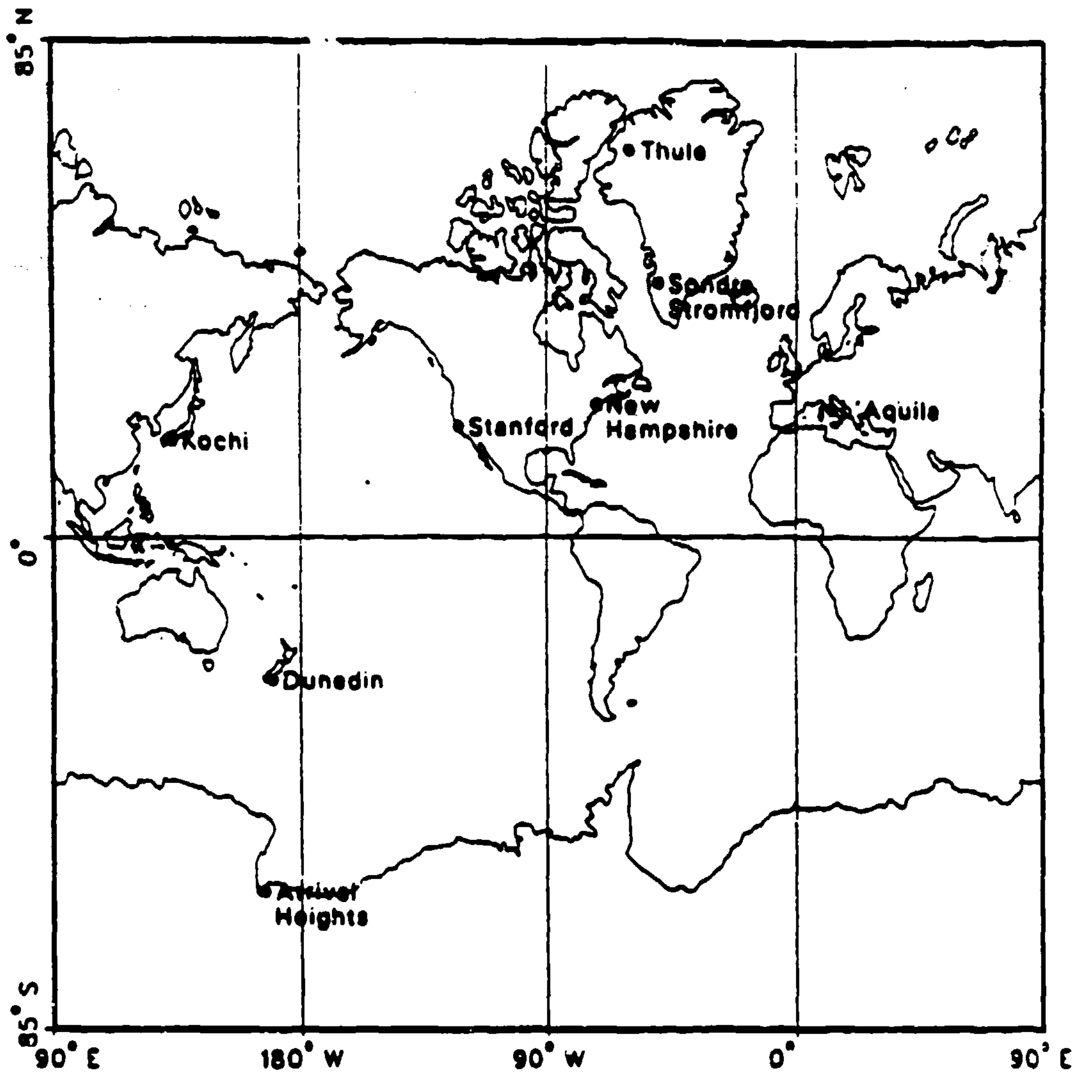



**Figure 1.** Locations of the eight ELF/VLF radiometer installations.

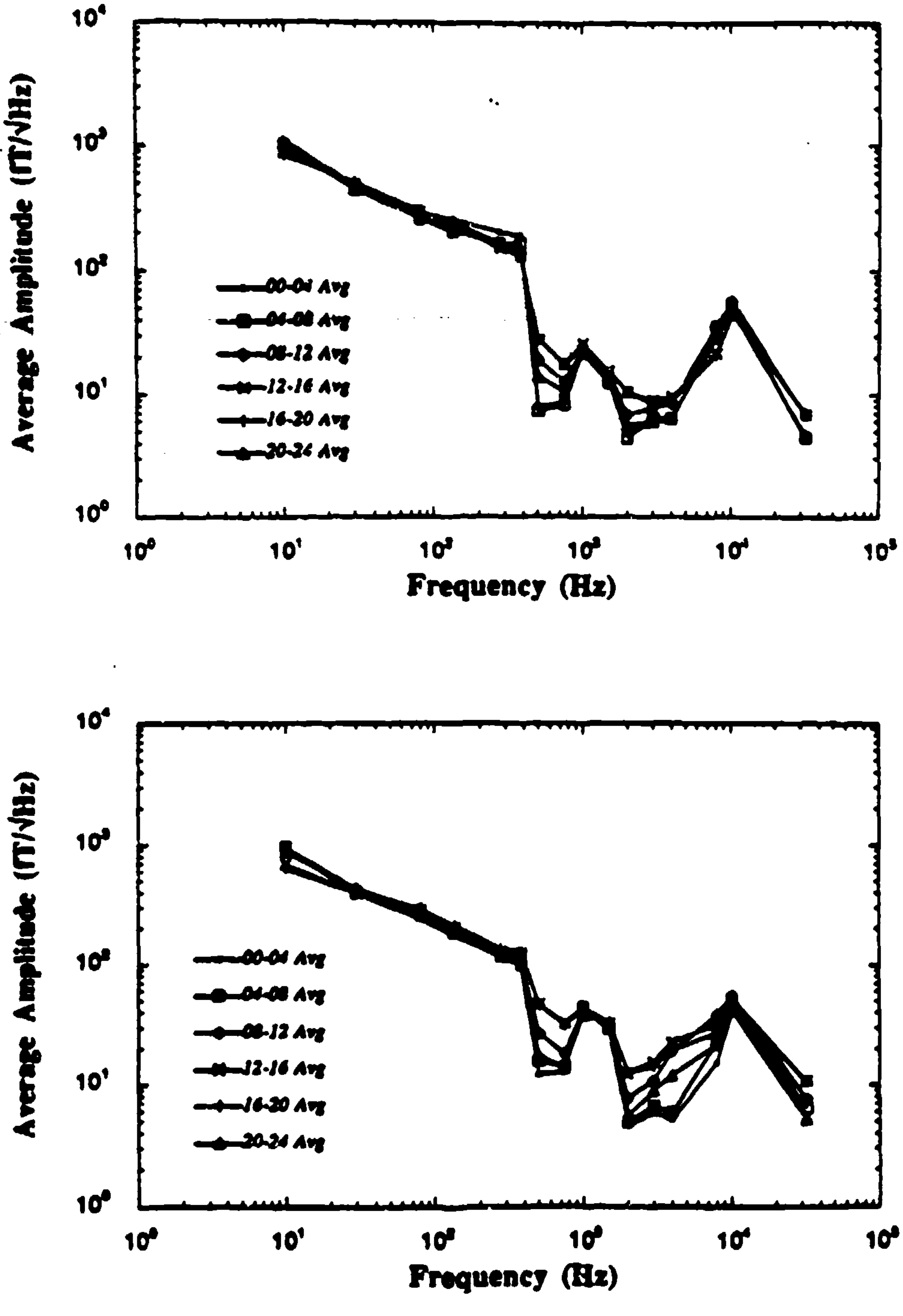



Figure 2. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Kochi, Japan, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Kochi, Japan, for Spring 1987.

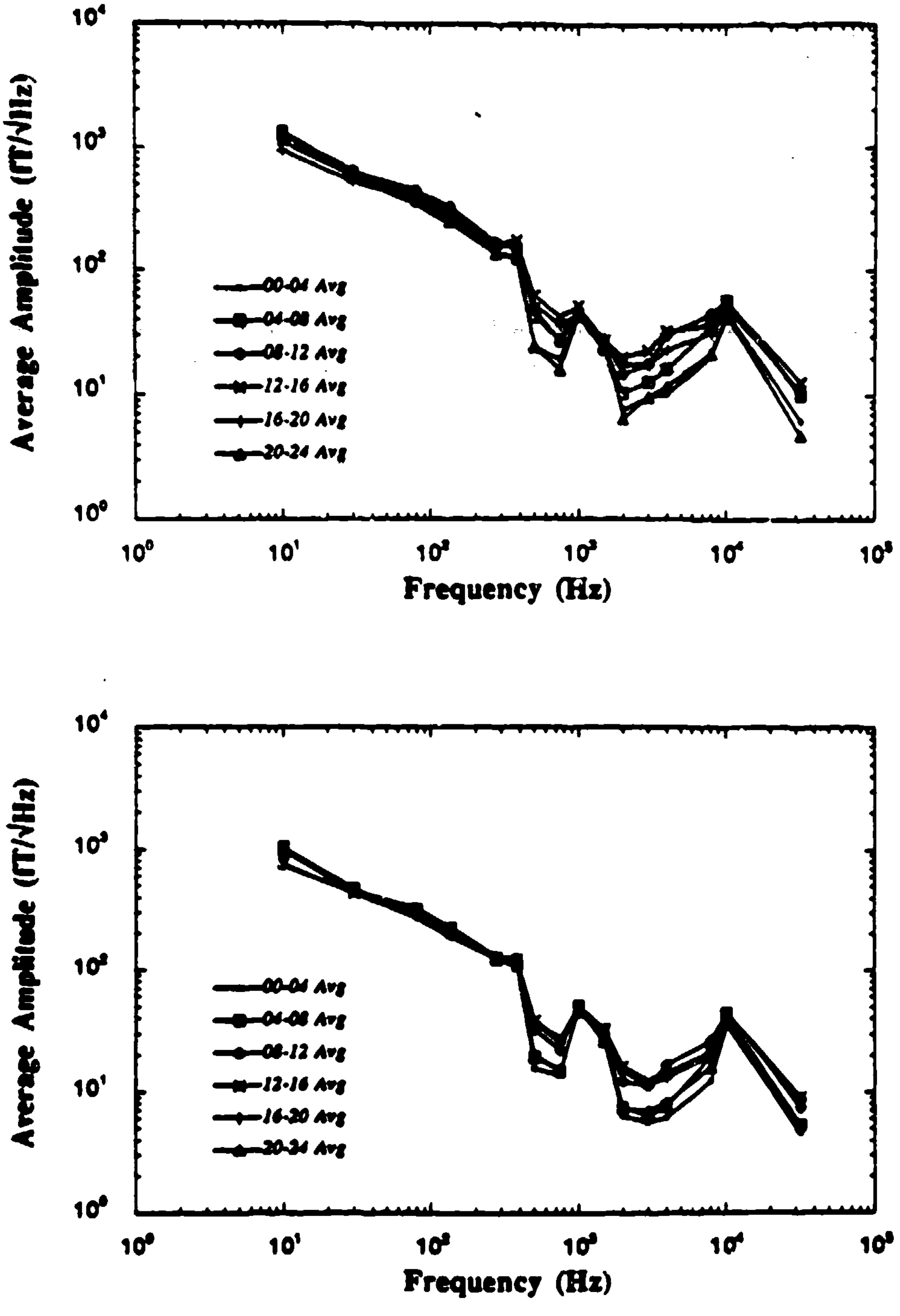
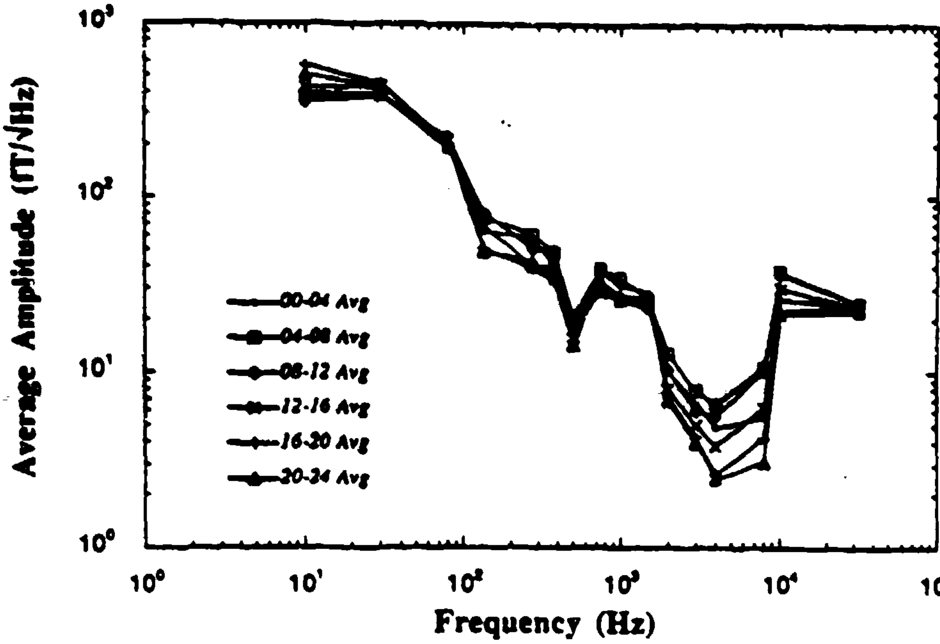



**Figure 3.** (Upper panel) Variation in average amplitudes of ELF/VLF noise at Kochi, Japan, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Kochi, Japan, for Autumn 1987.



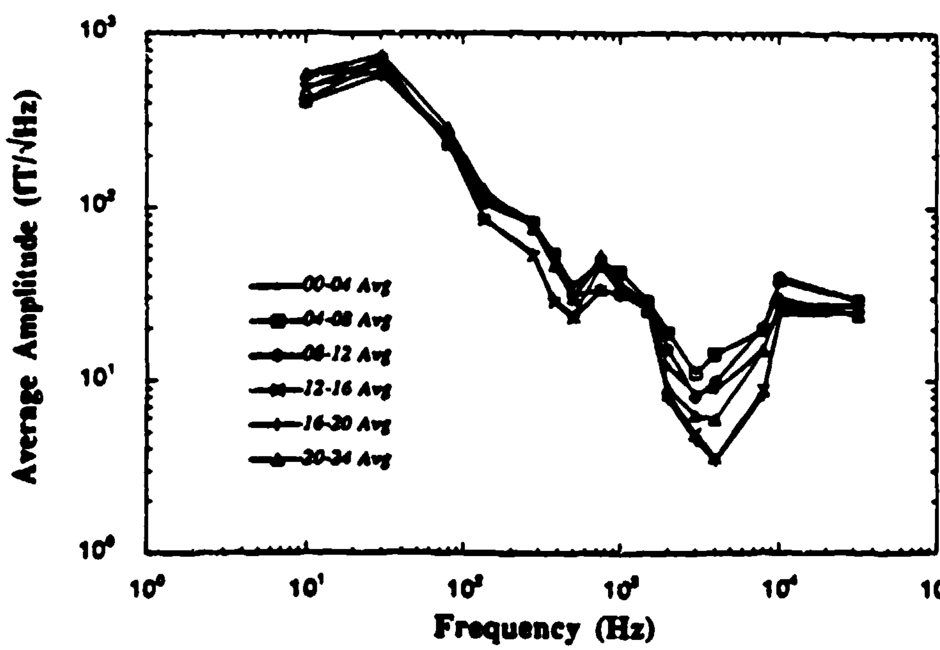




Figure 4. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Stanford, California, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Stanford, California, for Spring 1987.

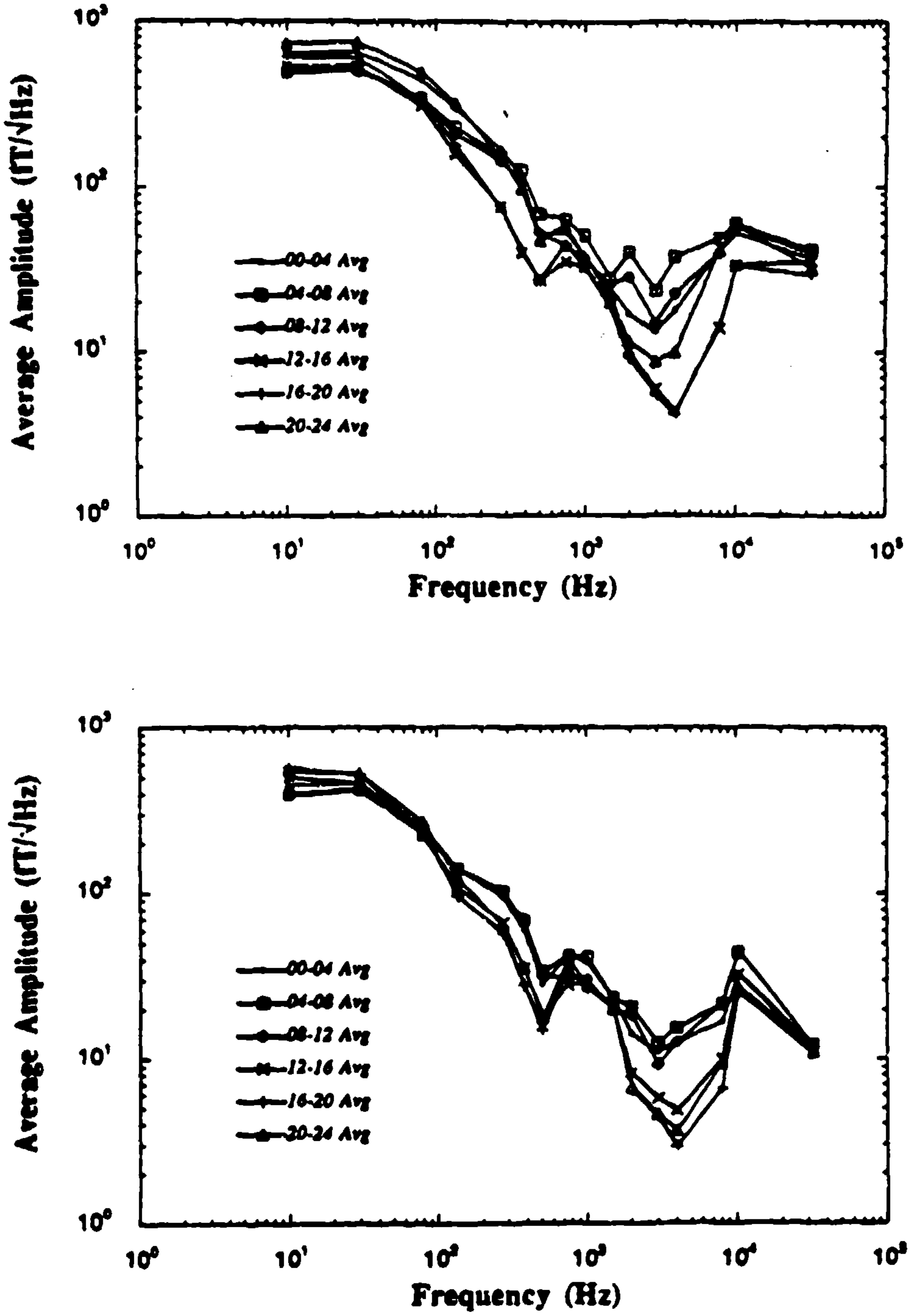
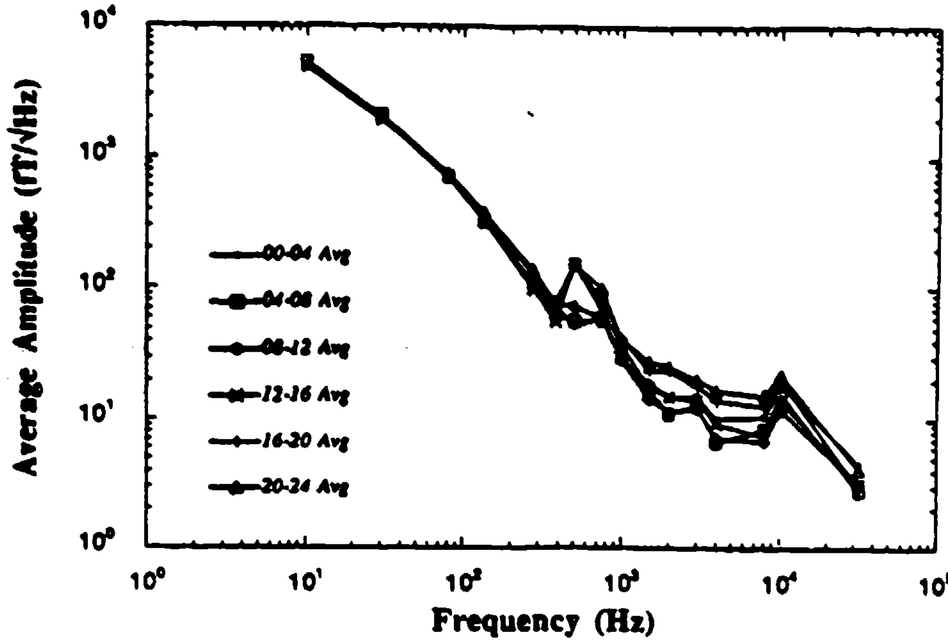



Figure 5. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Stanford, California, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Stanford, California, for Autumn 1987.



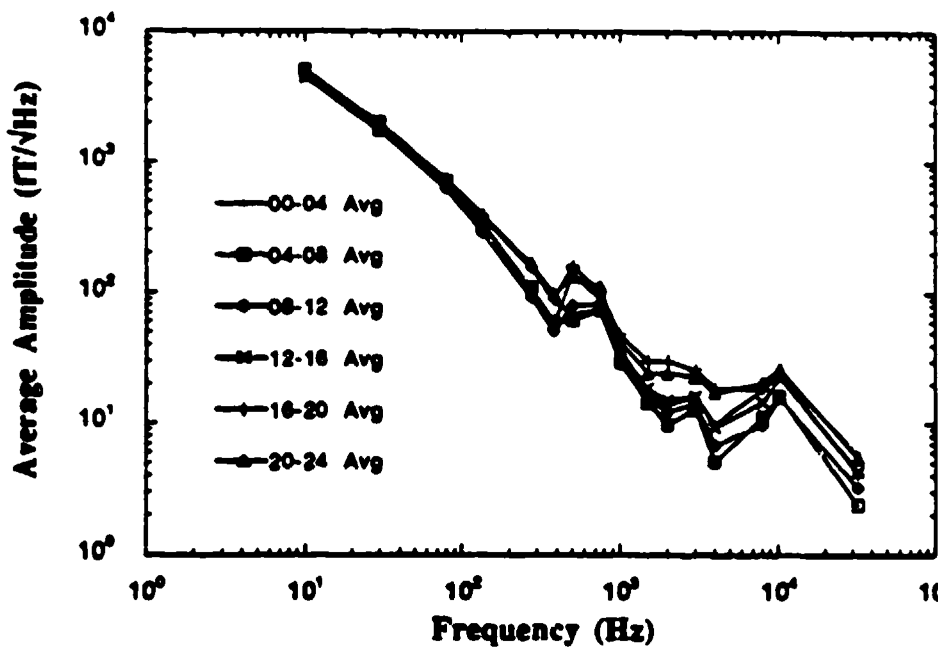




Figure 6. (Upper panel) Variation in average amplitudes of ELF/VLF noise at L'Aquila, Italy, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at L'Aquila, Italy, for Spring 1987.

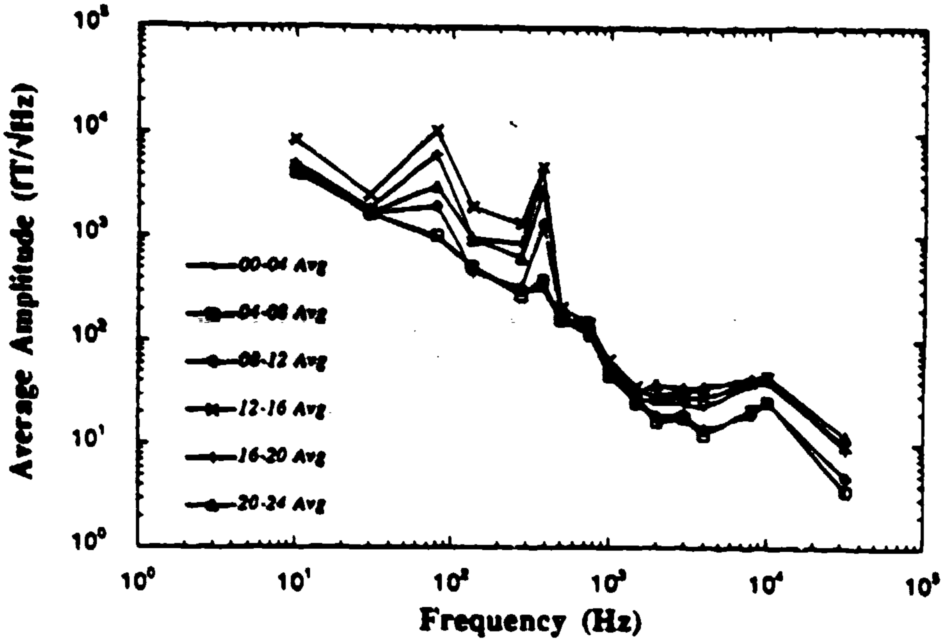
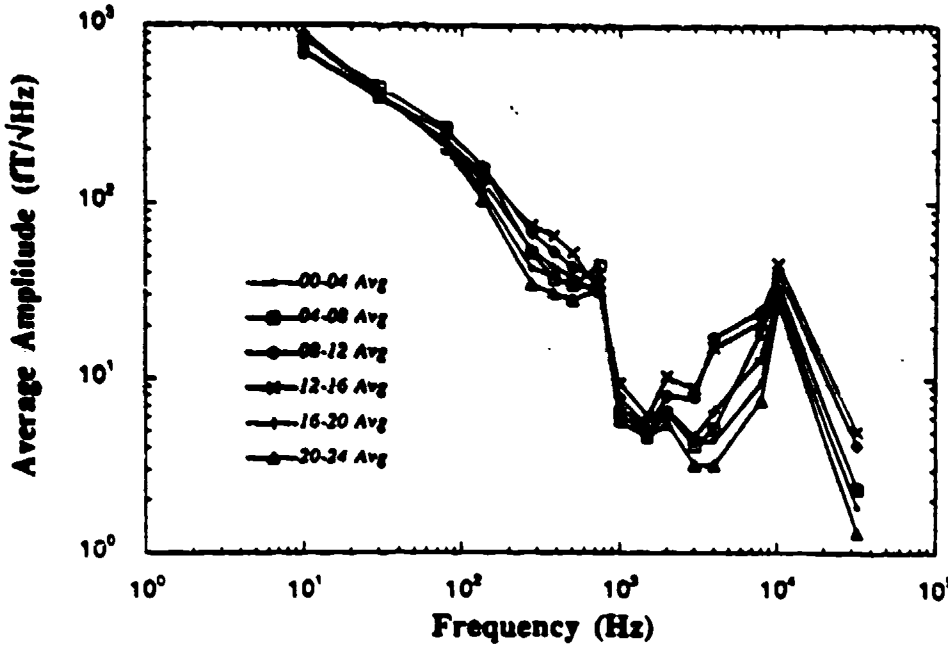



Figure 7. (Upper panel) Variation in average amplitudes of ELF/VLF noise at L'Aquila, Italy, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Insufficient data were available at L'Aquila for Autumn 1987.



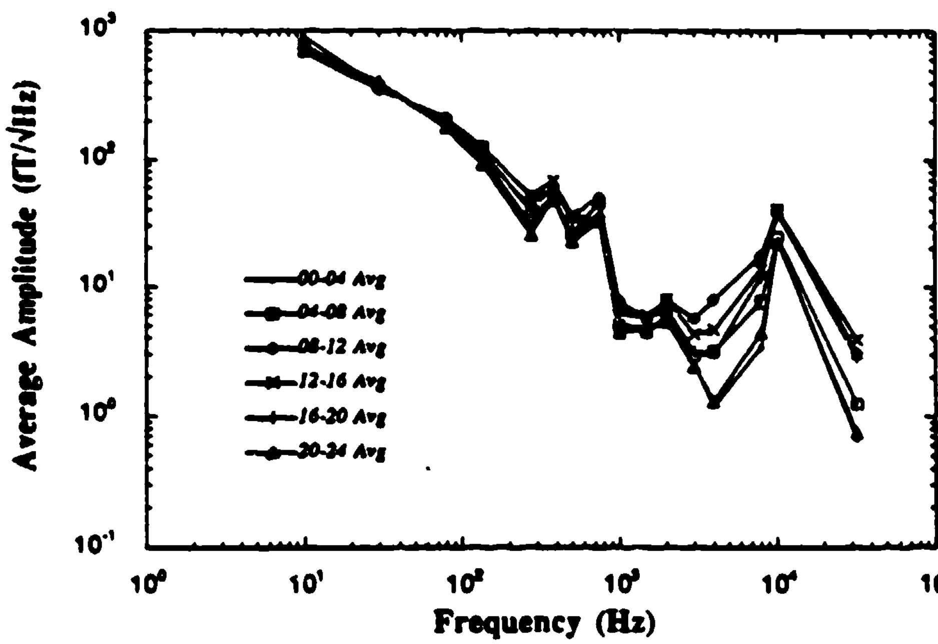




Figure 8. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Dunedin, New Zealand, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Dunedin, New Zealand, for Spring 1987.

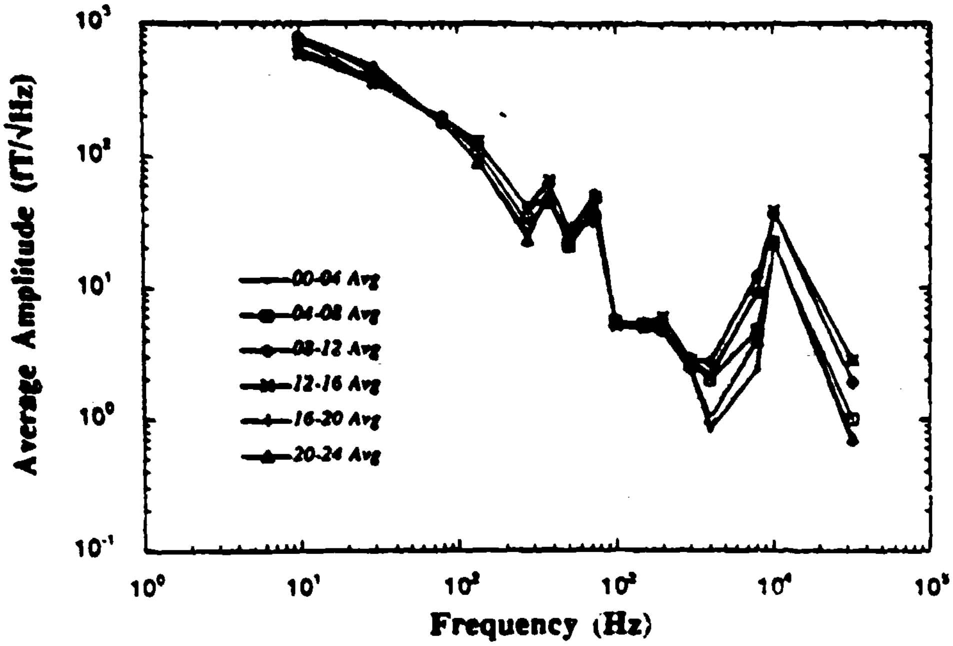



Figure 9. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Dunedin, New Zealand, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Insufficient data were available at Dunedin for Autumn 1987.

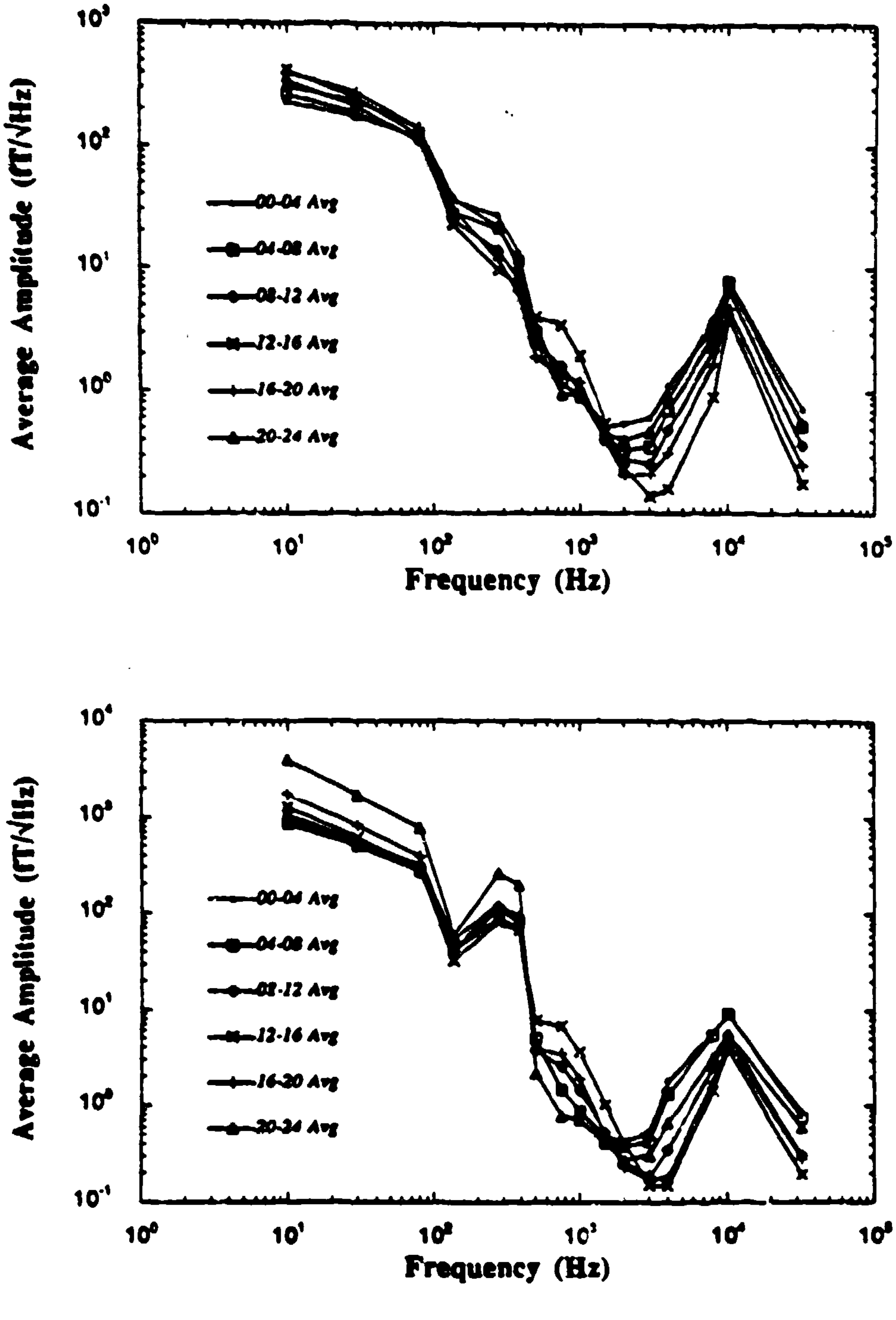



Figure 10. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Søndrestrømfjord, Greenland, during Winter 1986. T[illegible]asurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Søndrestrømfjord, Greenland, for Spring 1987.

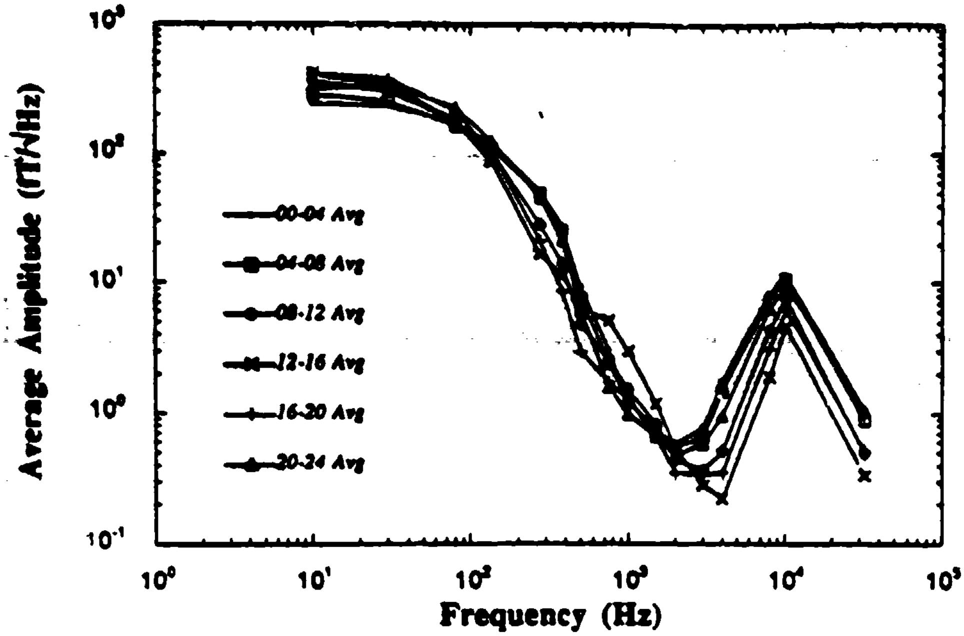



**Figure 11.** (Upper panel) Variation in average amplitudes of ELF/VLF noise at Søndrestrømfjord, Greenland, during Autumn 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. No data were available at Søndrestrømfjord for Summer 1987.

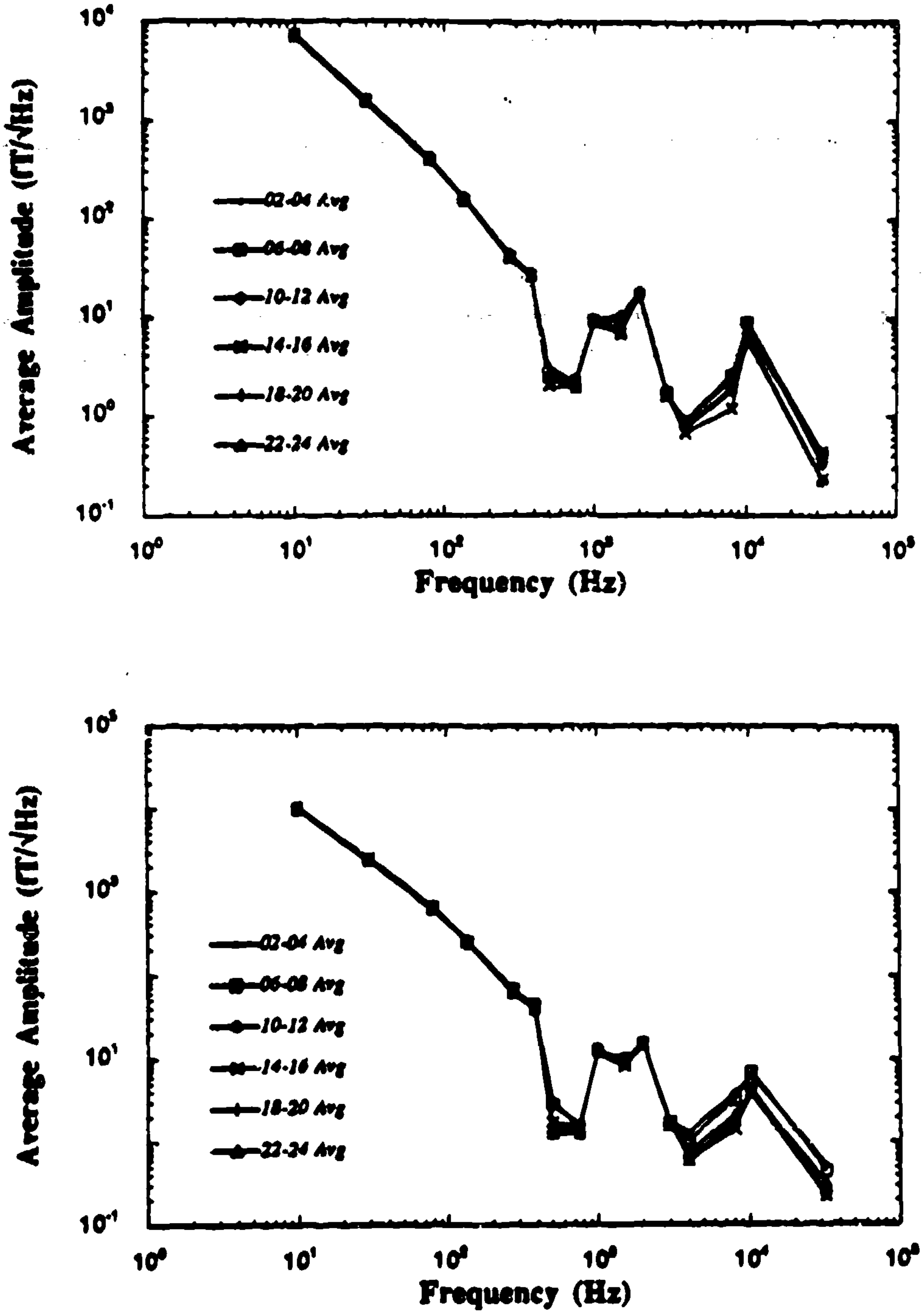
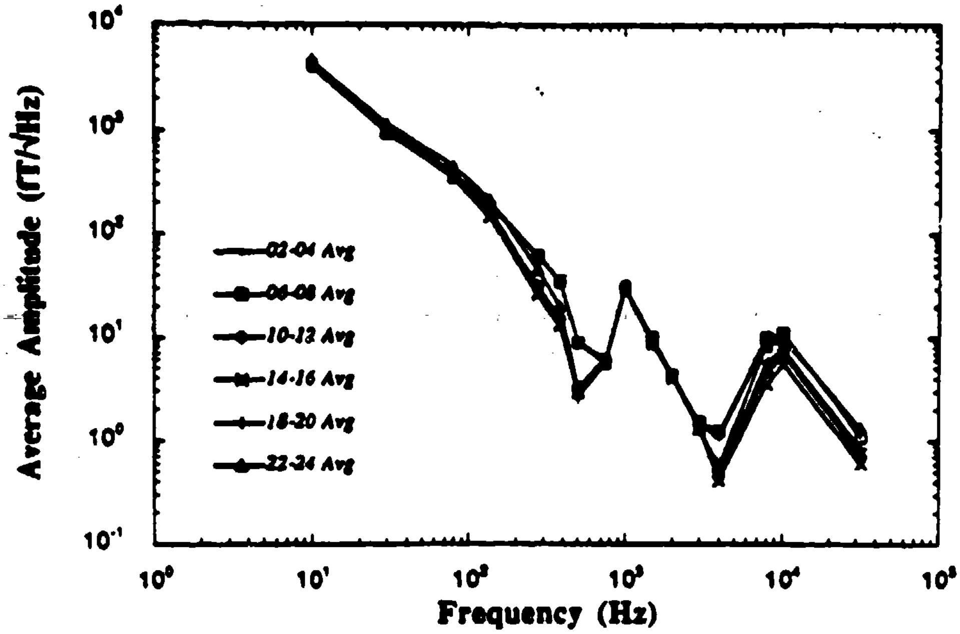



Figure 12. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Thule, Greenland, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Measurements made during hours of ionosonde operation have been excluded. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Thule, Greenland, for Spring 1987.



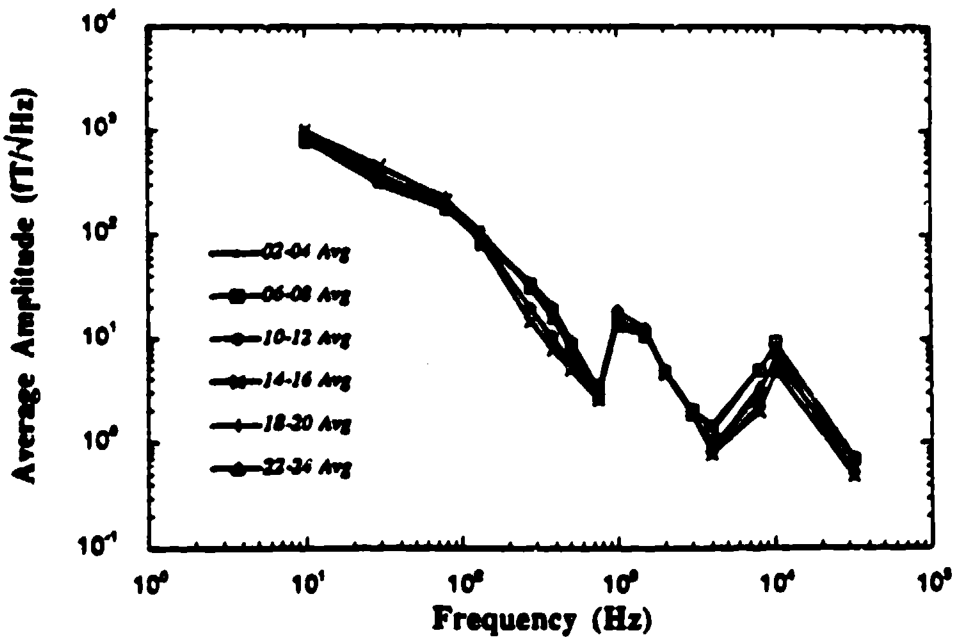




**Figure 13.** (Upper panel) Variation in average amplitudes of ELF/VLF noise at Thule, Greenland, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Measurements made during hours of ionosonde operation have been excluded. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Thule, Greenland, for Autumn 1987.

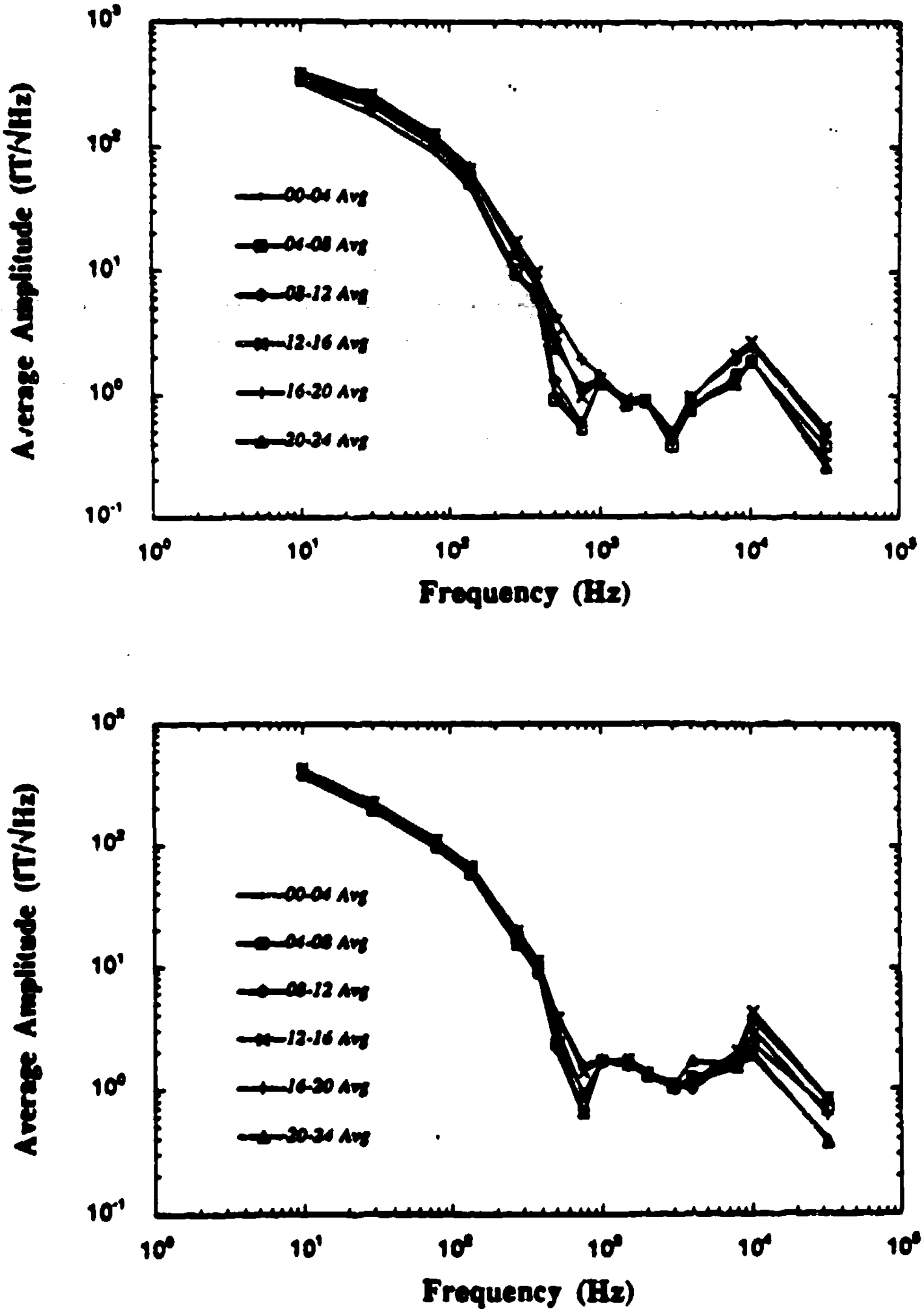



**Figure 14.** (Upper panel) Variation in average amplitudes of ELF/VLF noise at Arrival Heights, Antarctica, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Arrival Heights, Antarctica, for Spring 1987.

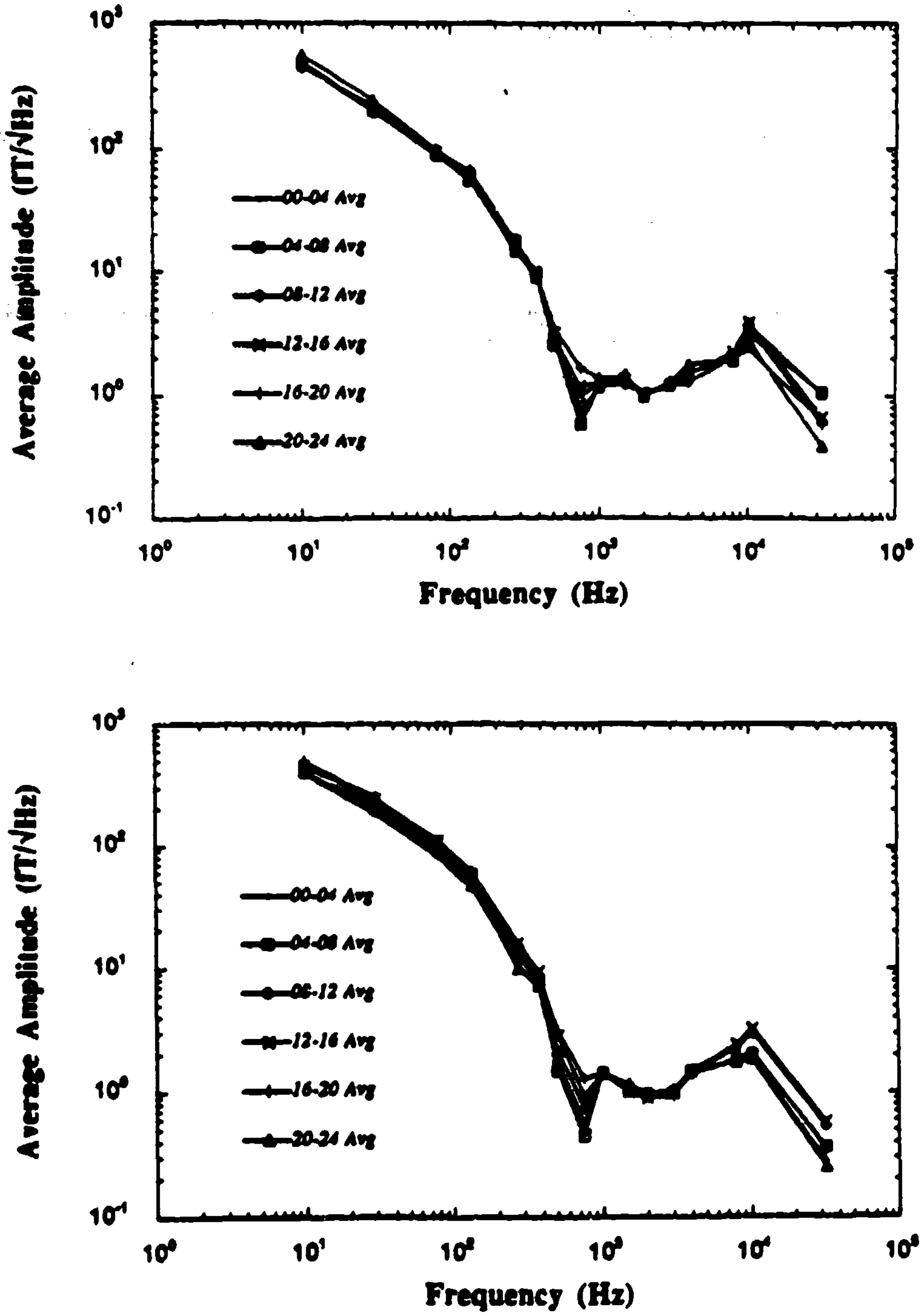
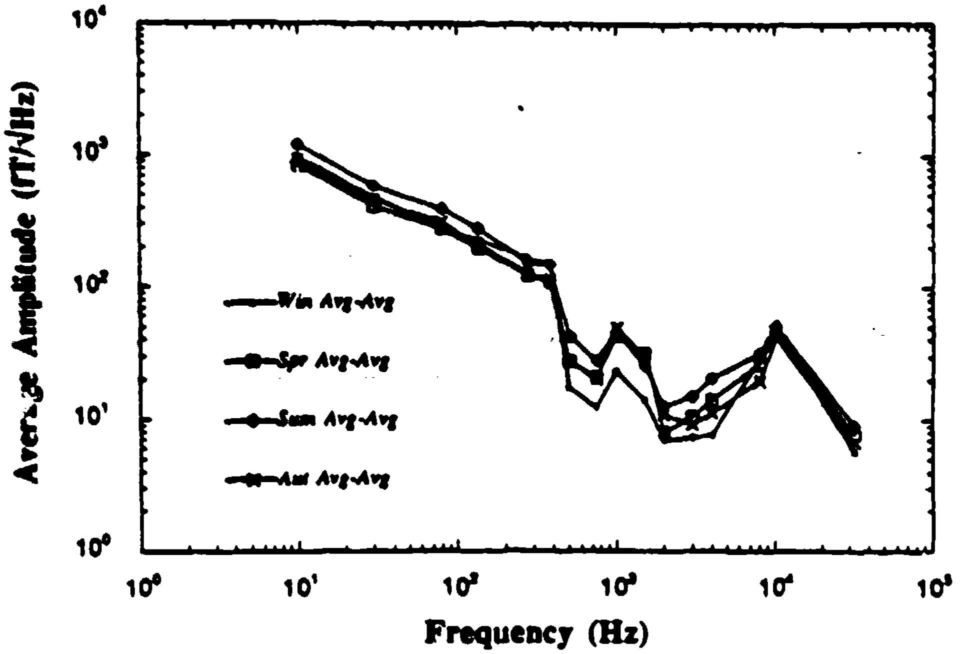



**Figure 15.** (Upper panel) Variation in average amplitudes of ELF/VLF noise at Arrival Heights, Antarctica, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Arrival Heights, Antarctica, for Autumn 1987.



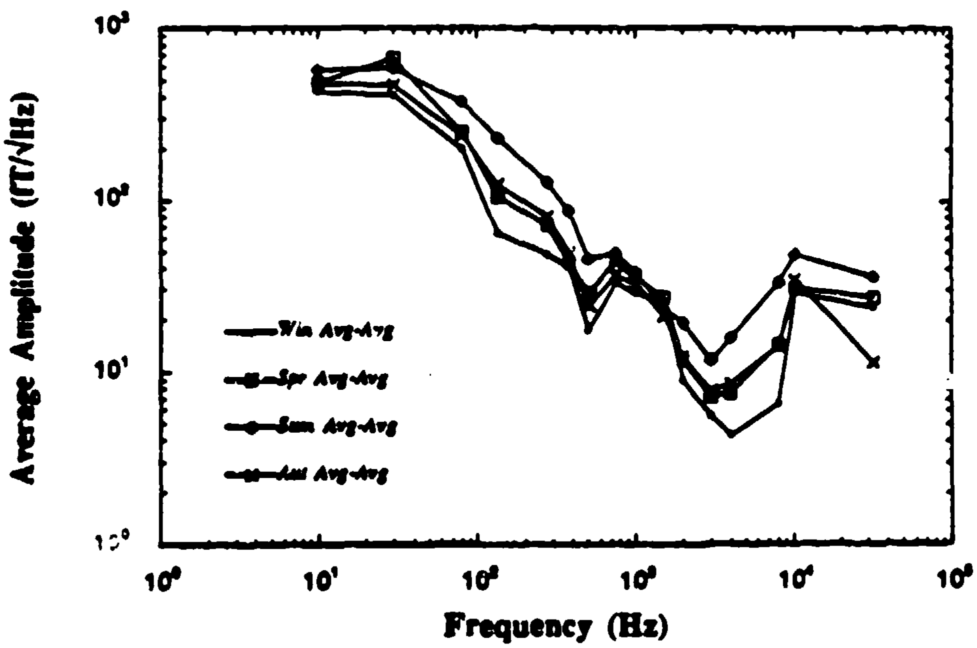




**Figure 16.** (Upper panel) Variation in average amplitudes of ELF/VLF noise at Kochi, Japan, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Stanford, California, for the 1986–1987 year.

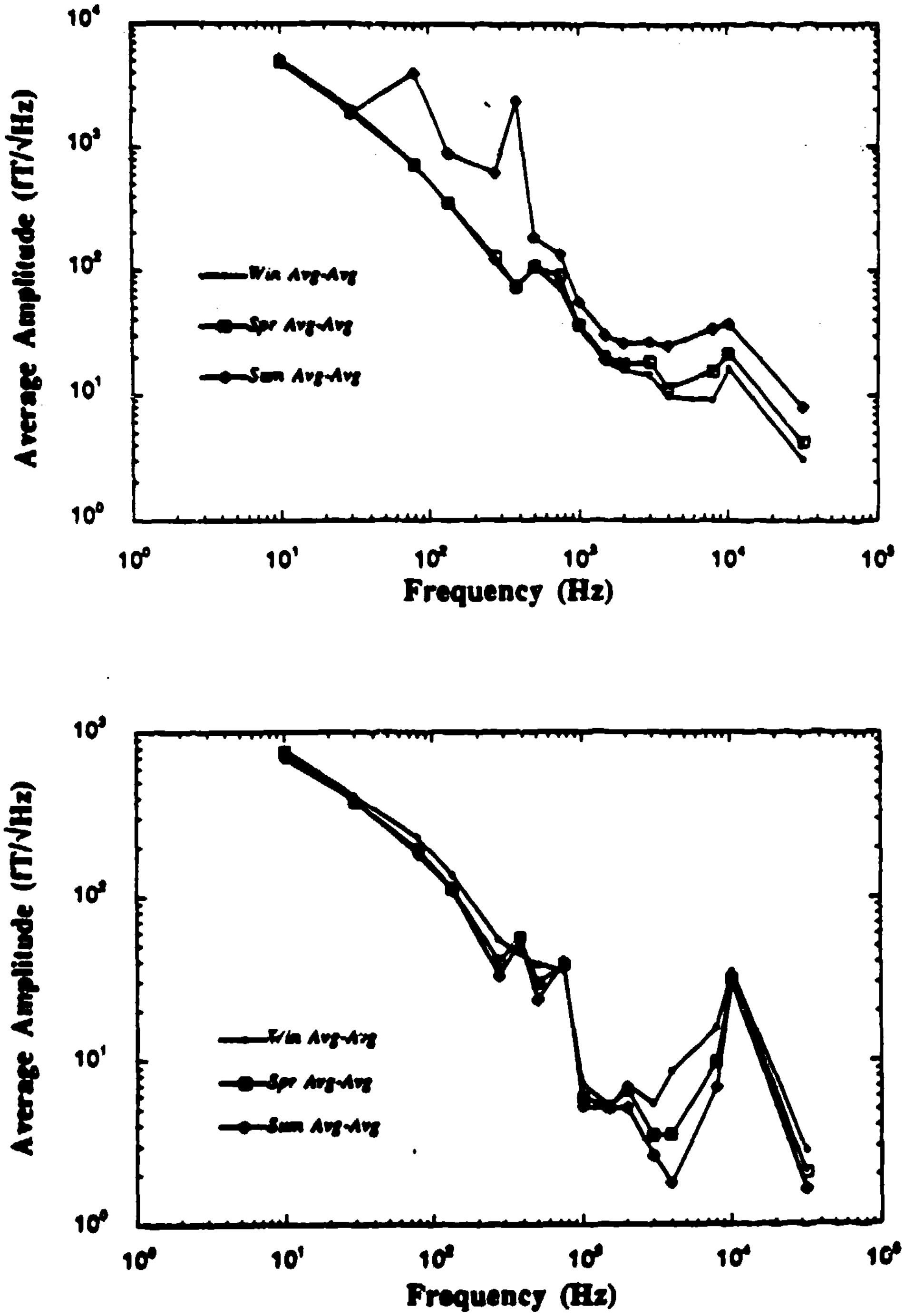



Figure 17. (Upper panel) Variation in average amplitudes of ELF/VLF noise at L'Aquila, Italy, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Dunedin, New Zealand, for the 1986–1987 year.

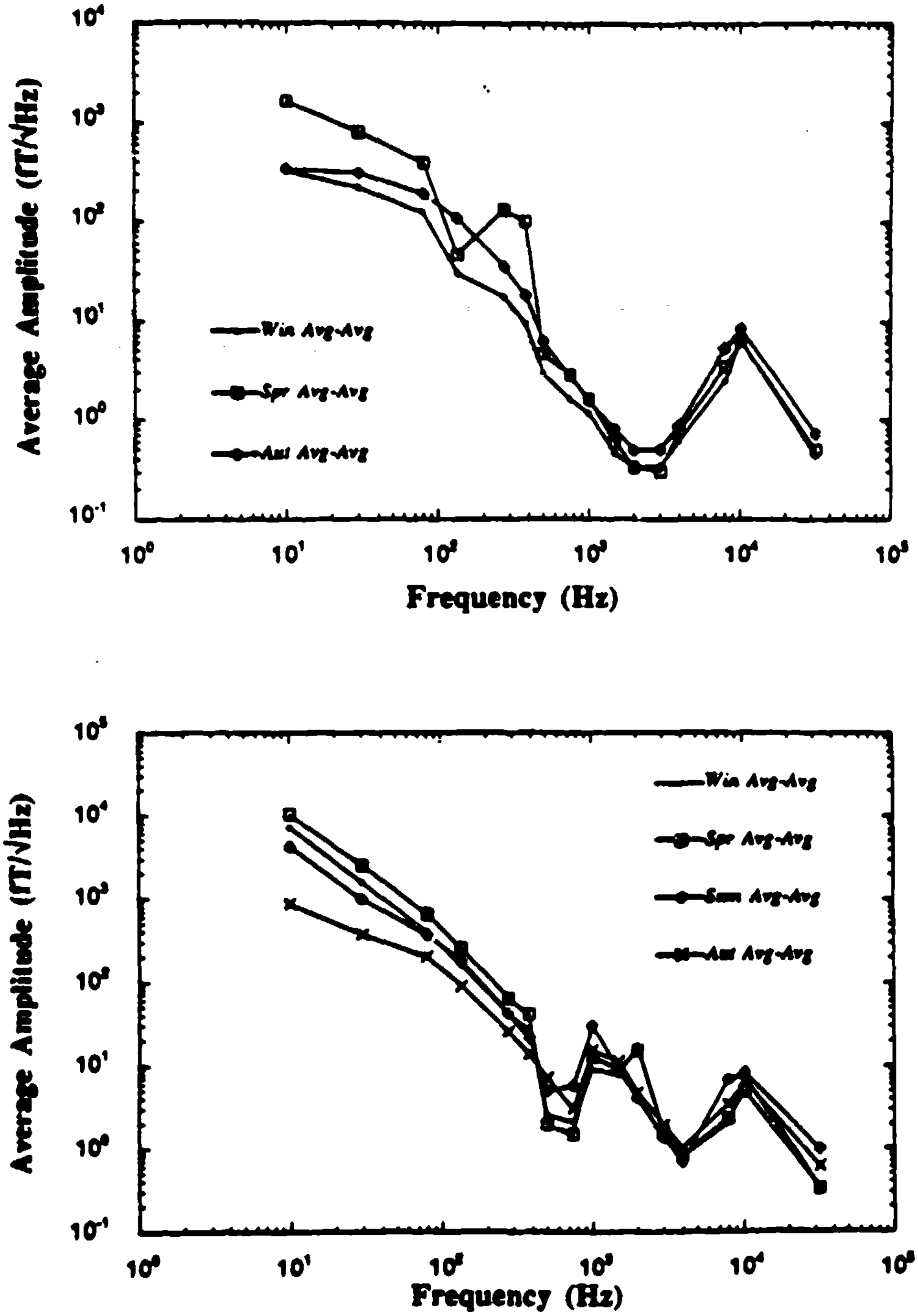



Figure 18. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Søndrestrømfjord, Greenland, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season. (Lower panel) Variation in average amplitudes of ELF/VLF noise at Thule, Greenland, for the 1986–1987 year. Measurements made during hours of ionosonde operation have been excluded.

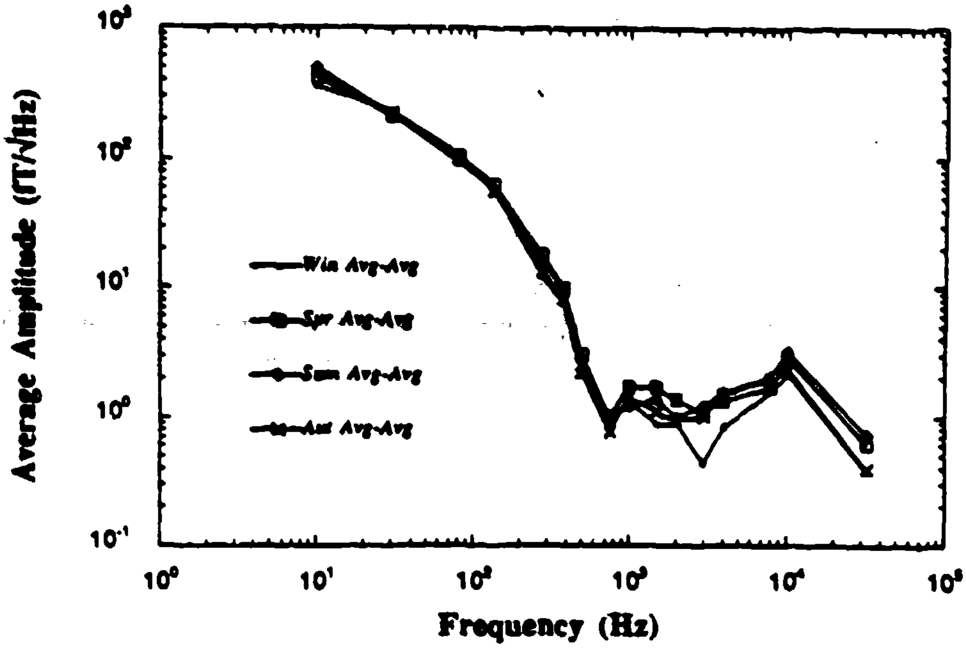



Figure 19. (Upper panel) Variation in average amplitudes of ELF/VLF noise at Arrival Heights, Antarctica, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season.

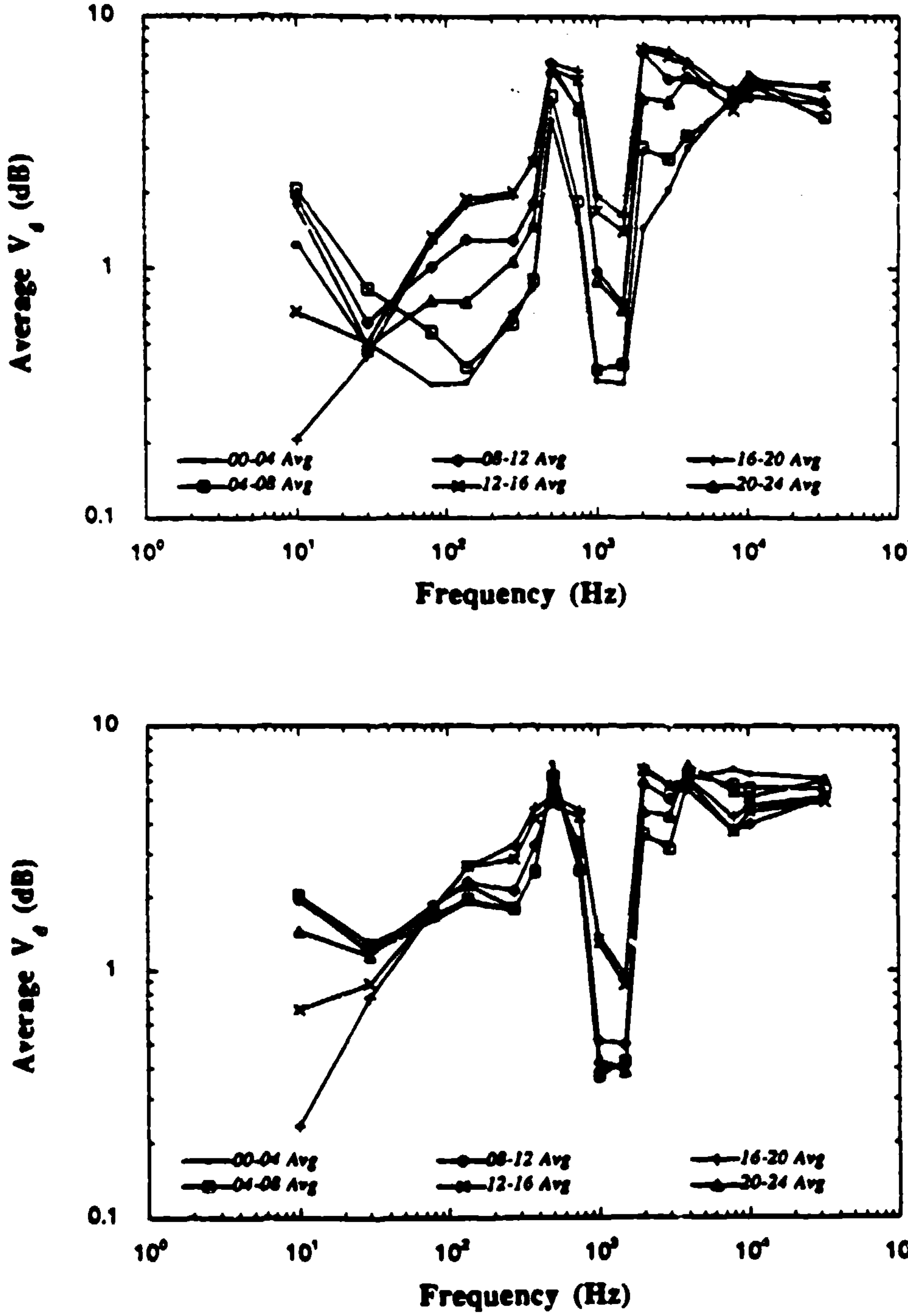



Figure 20. (Upper panel) Variations in $V_d$ amplitudes of ELF/VLF noise at Kochi, Japan, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in $V_d$ of ELF/VLF noise at Kochi, Japan, for Spring 1987.

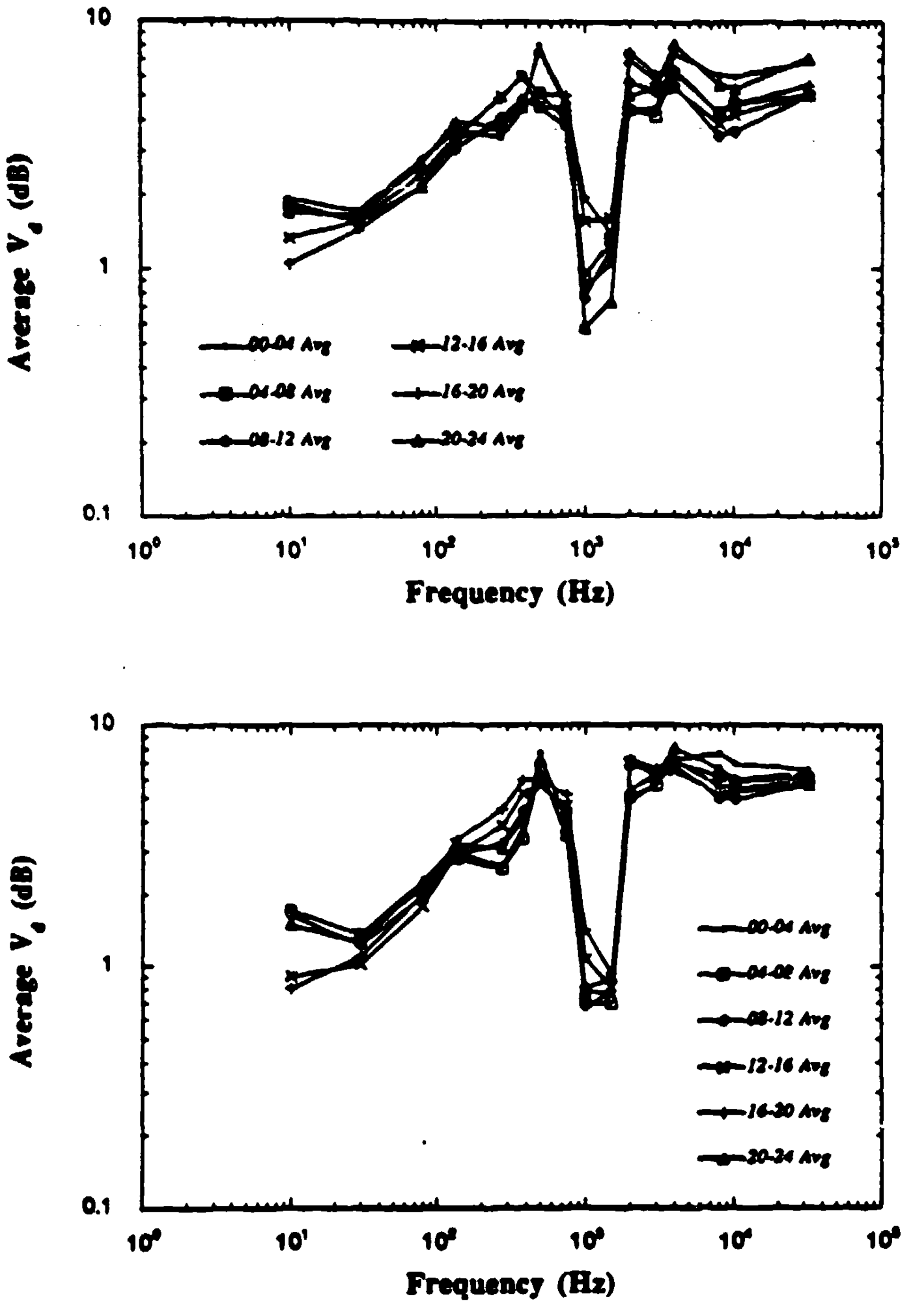
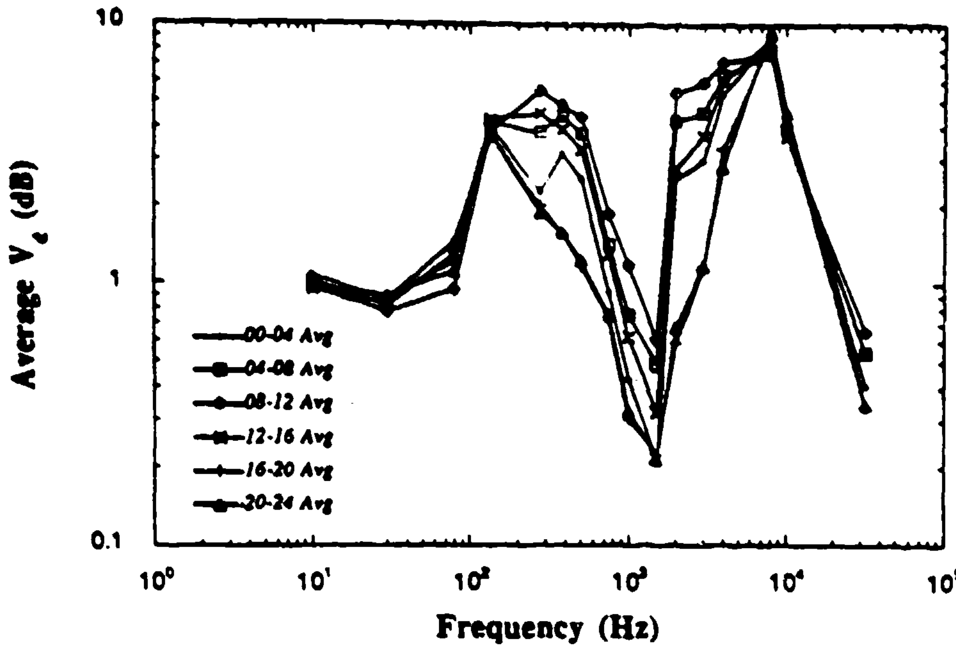



**Figure 21.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Kochi, Japan, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Kochi, Japan, for Autumn 1987.



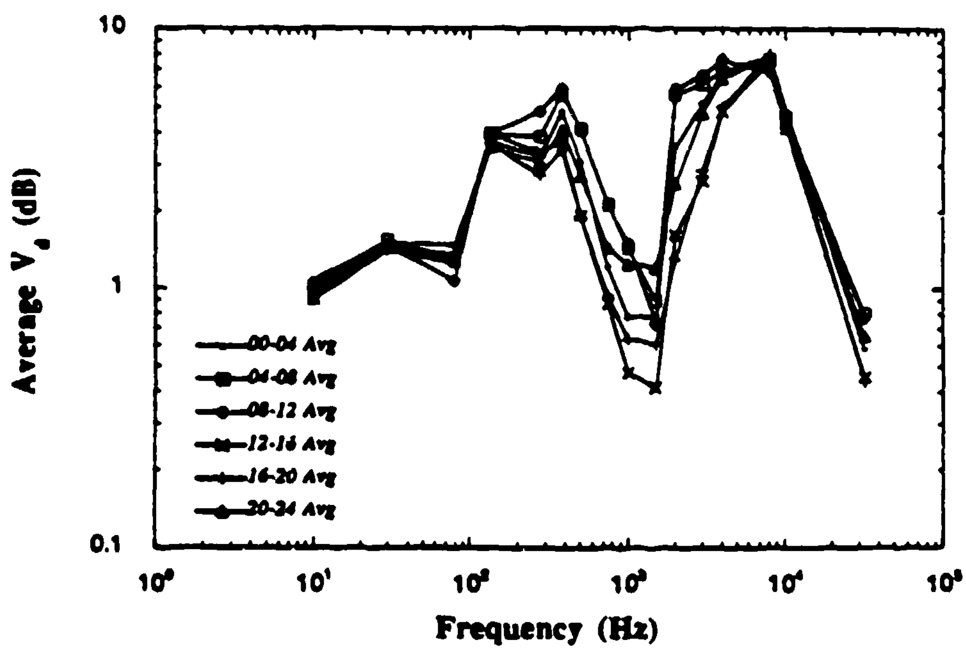




Figure 22. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Stanford, California, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Stanford, California, for Spring 1987.

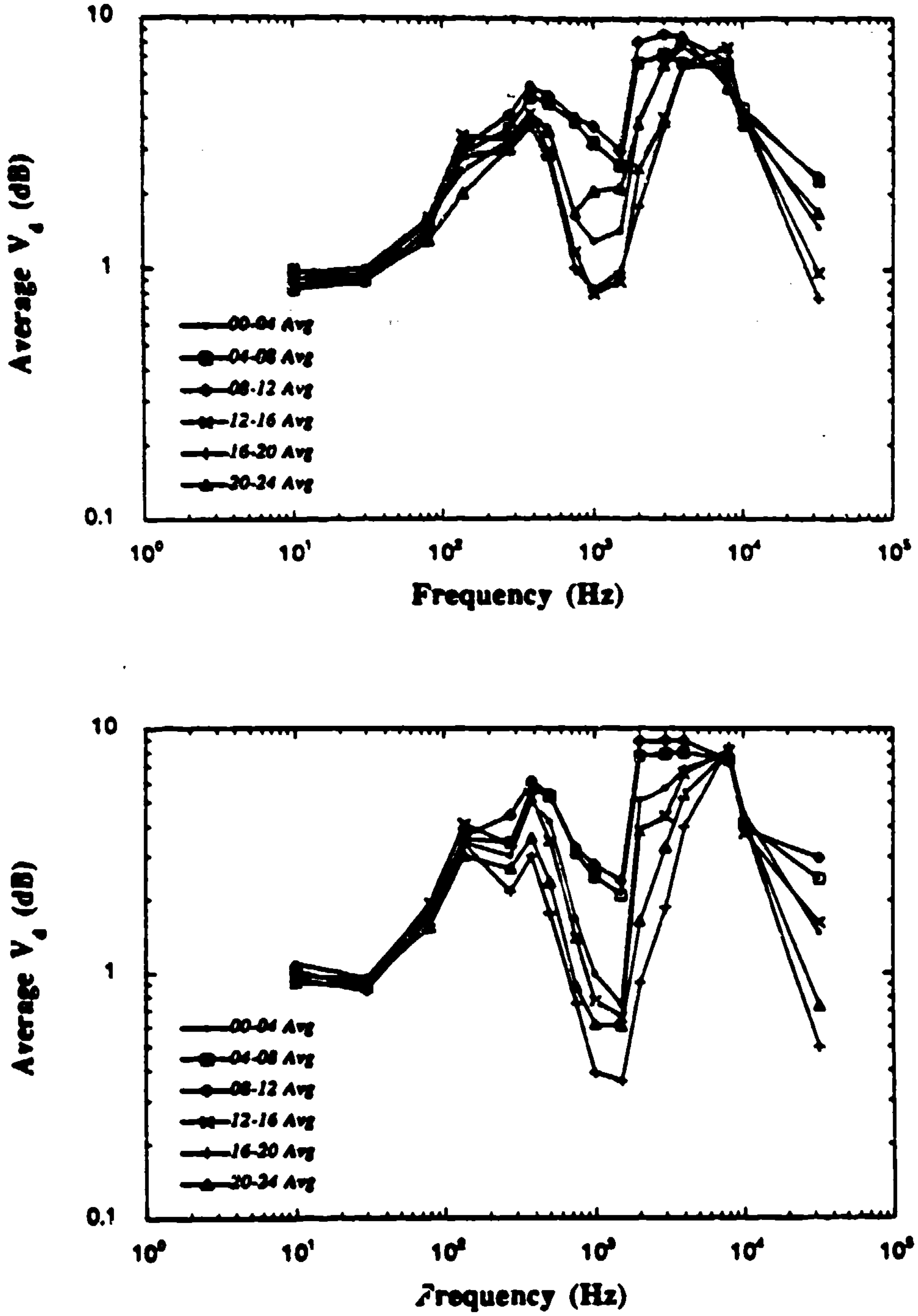



Figure 23. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Stanford, California, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Stanford, California, for Autumn 1987.

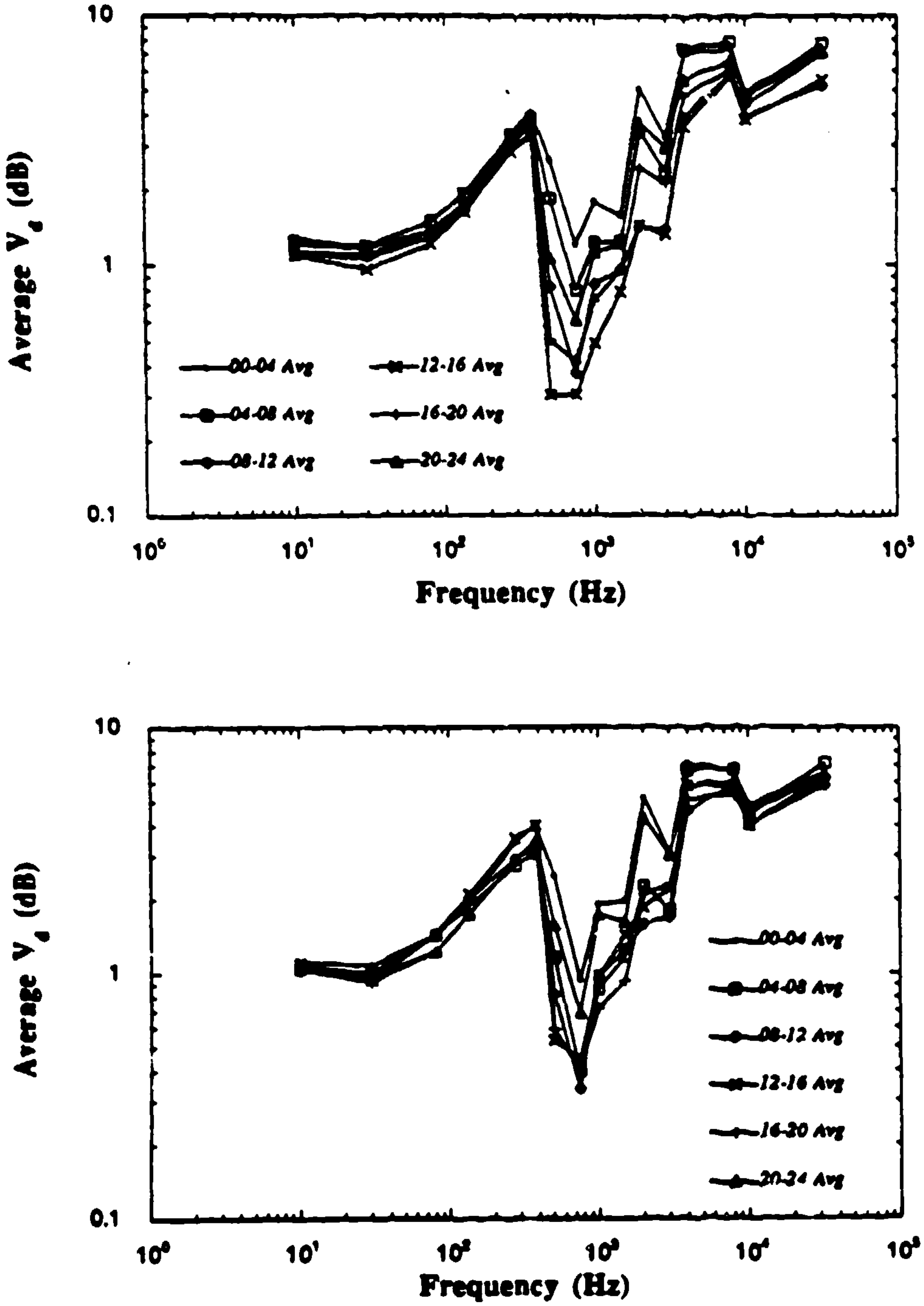



Figure 24. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at L'Aquila, Italy, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at L'Aquila, Italy, for Spring 1987.

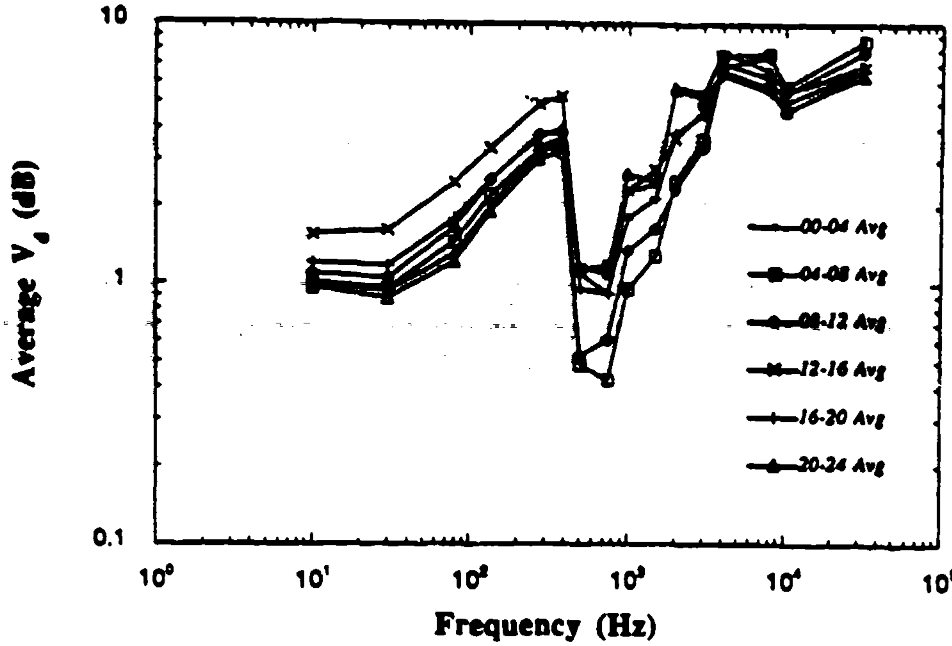



**Figure 25.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at L'Aquila, Italy, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Insufficient data were available at L'Aquila for Autumn 1987.

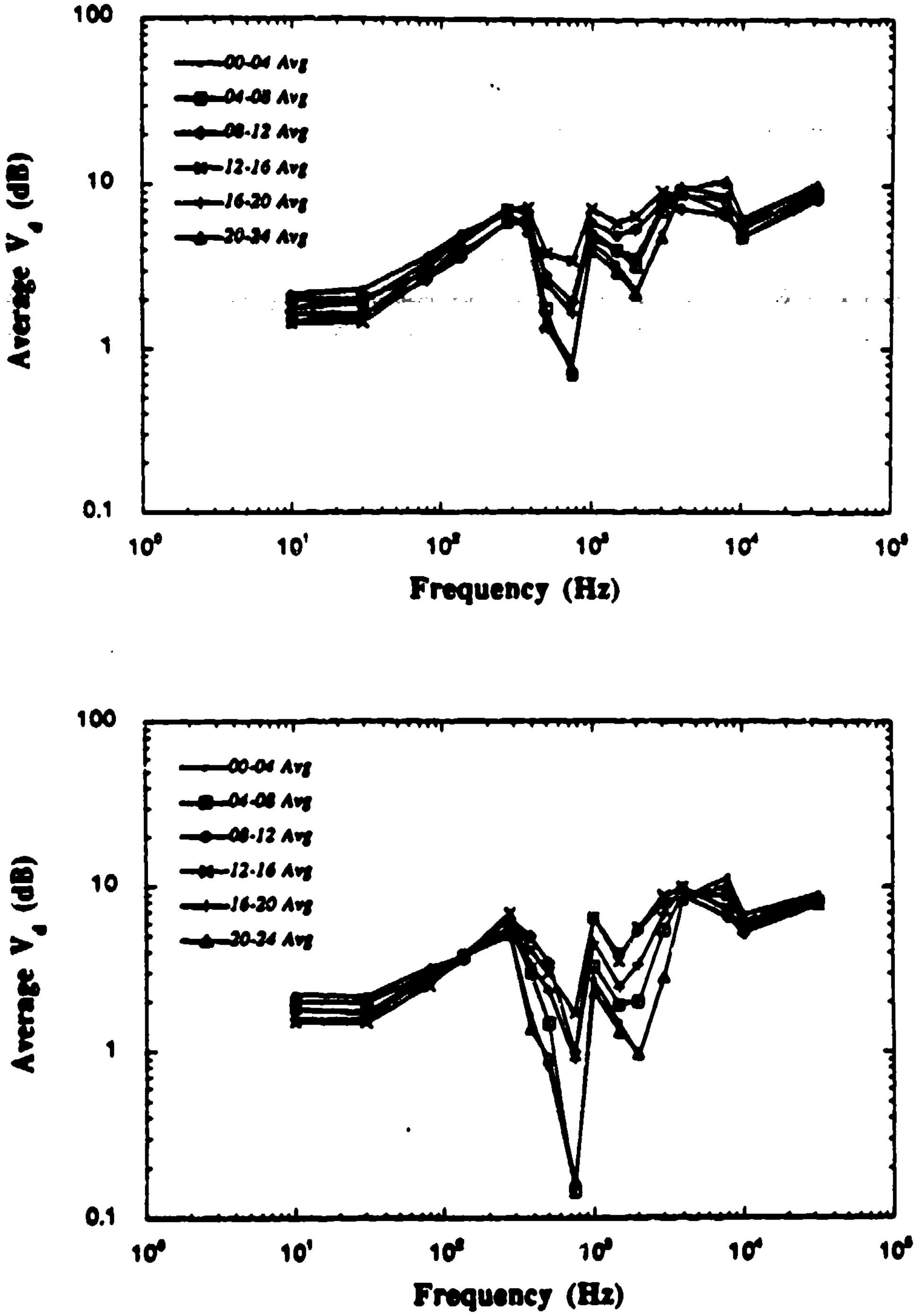



**Figure 26.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Dunedin, New Zealand, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Dunedin, New Zealand, for Spring 1987.

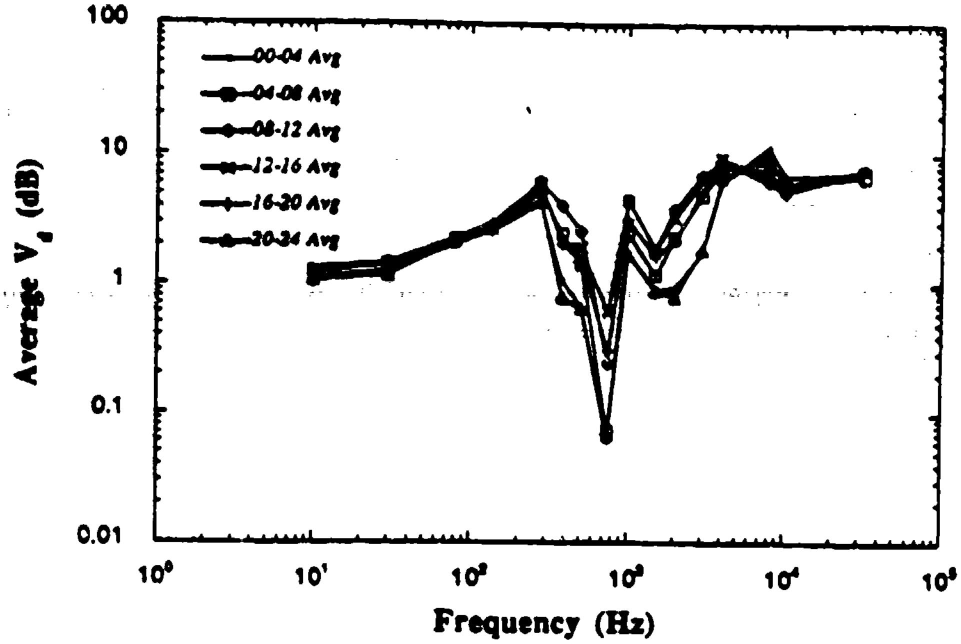
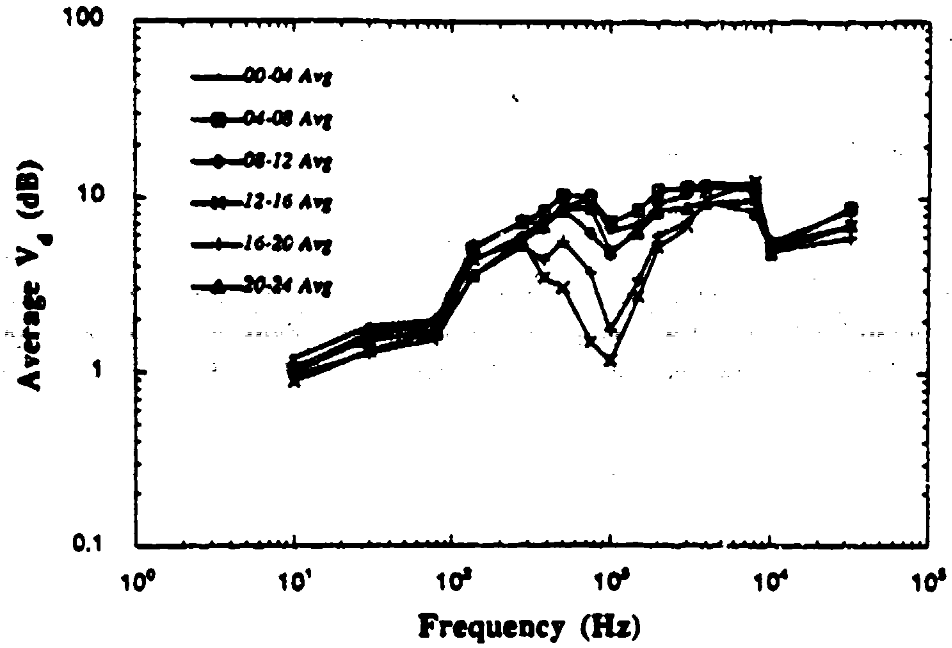



**Figure 27.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Dunedin, New Zealand, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Insufficient data were available at Dunedin for Autumn 1987.



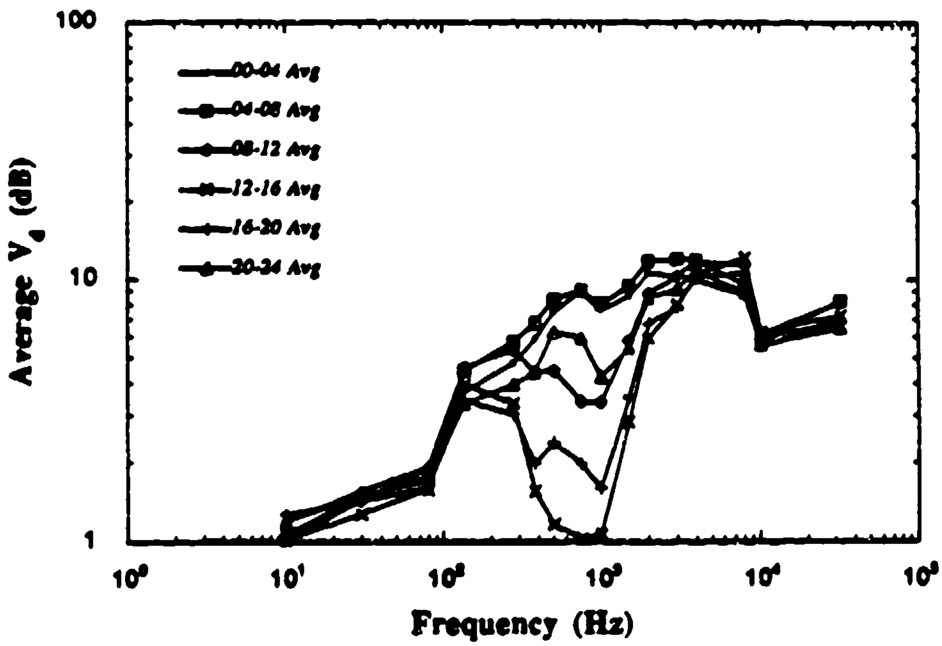




**Figure 28.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Søndrestrømfjord, Greenland, during Winter 1986. The measurements have been averaged at each frequenc·· for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Søndrestrømfjord, Greenland, for Spring 1987.

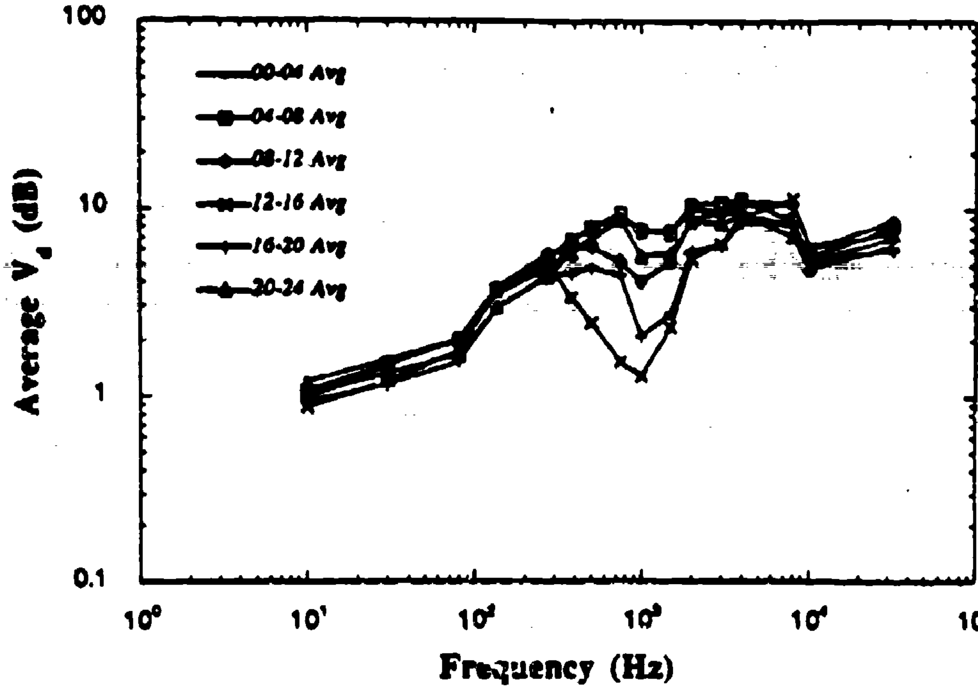
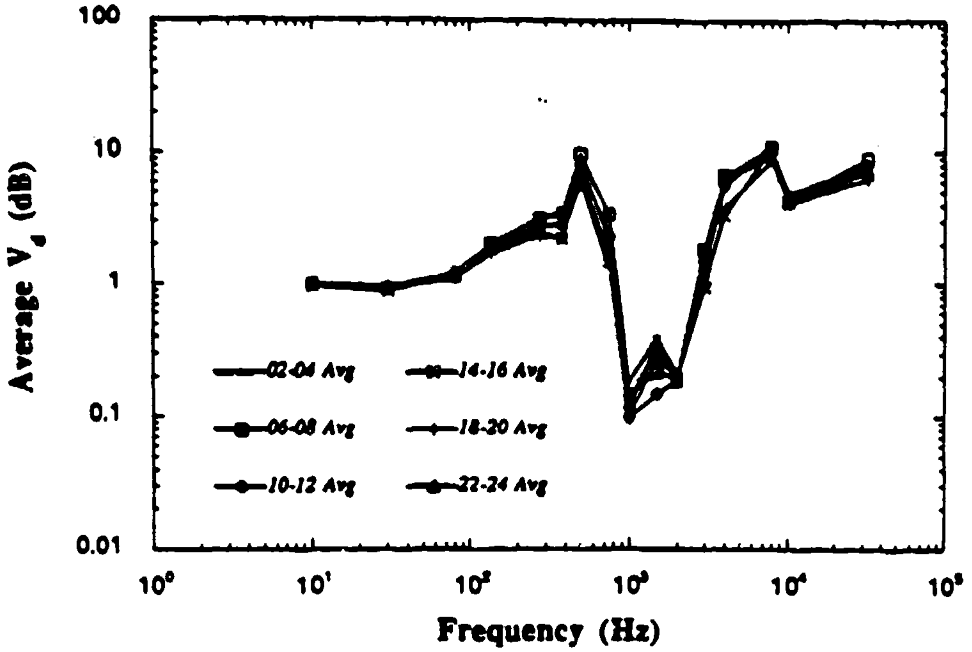



**Figure 29.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Søndrestrømfjord, Greenland, during Autumn 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. No data were available at Søndrestrømfjord for Summer 1987.



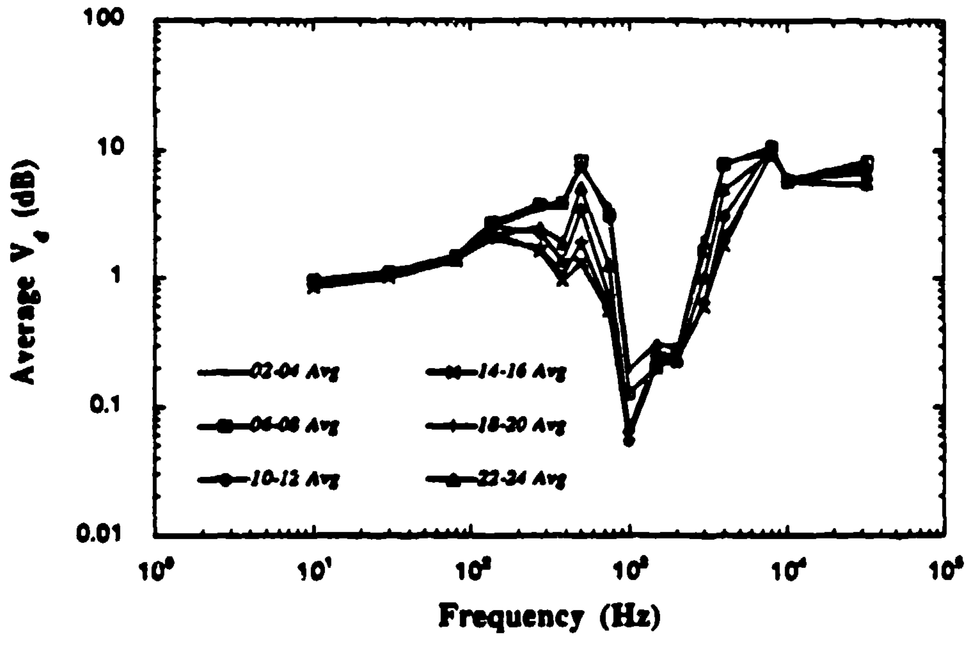




**Figure 30.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Thule, Greenland, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Measurements made during hours of ionosonde operation have been excluded. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Thule, Greenland, for Spring 1987.

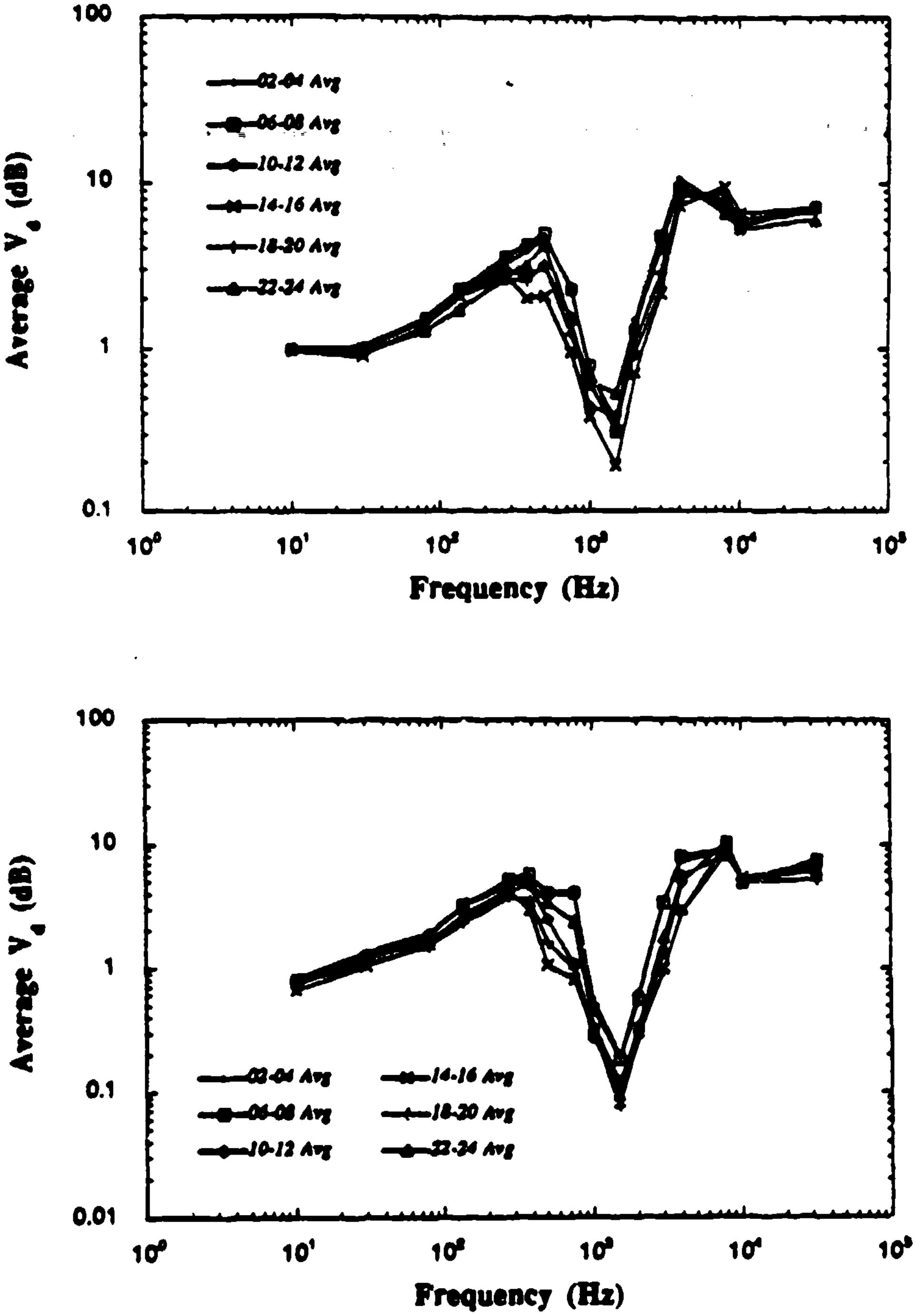



**Figure 31.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Thule, Greenland, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. Measurements made during hours of ionosonde operation have been excluded. (Lower panel) Variation in $V_d$ of ELF/VLF noise at Thule, Greenland for Autumn 1987.

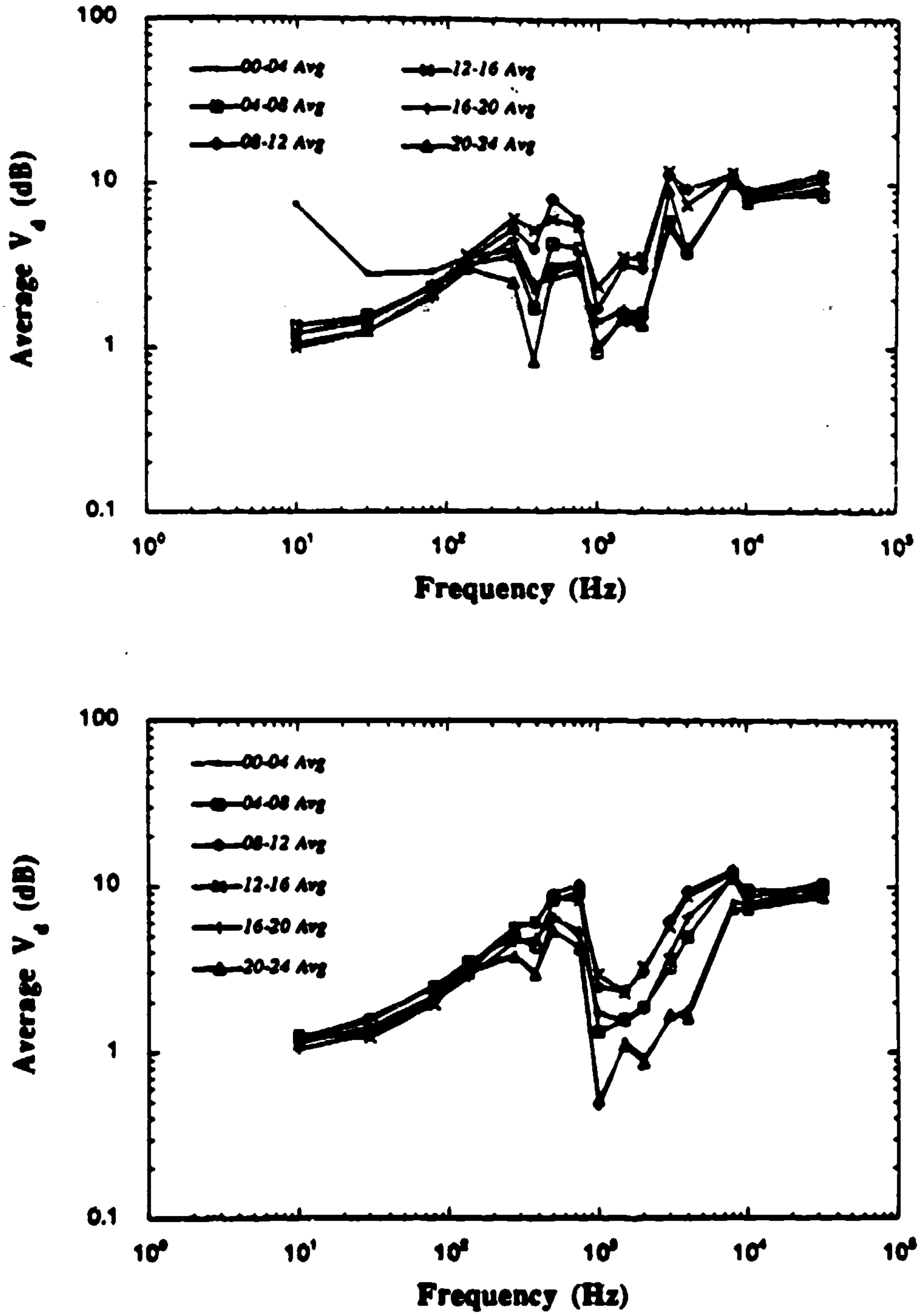



Figure 32. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Arrival Heights, Antarctica, during Winter 1986. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Arrival Heights, Antarctica, for Spring 1987.

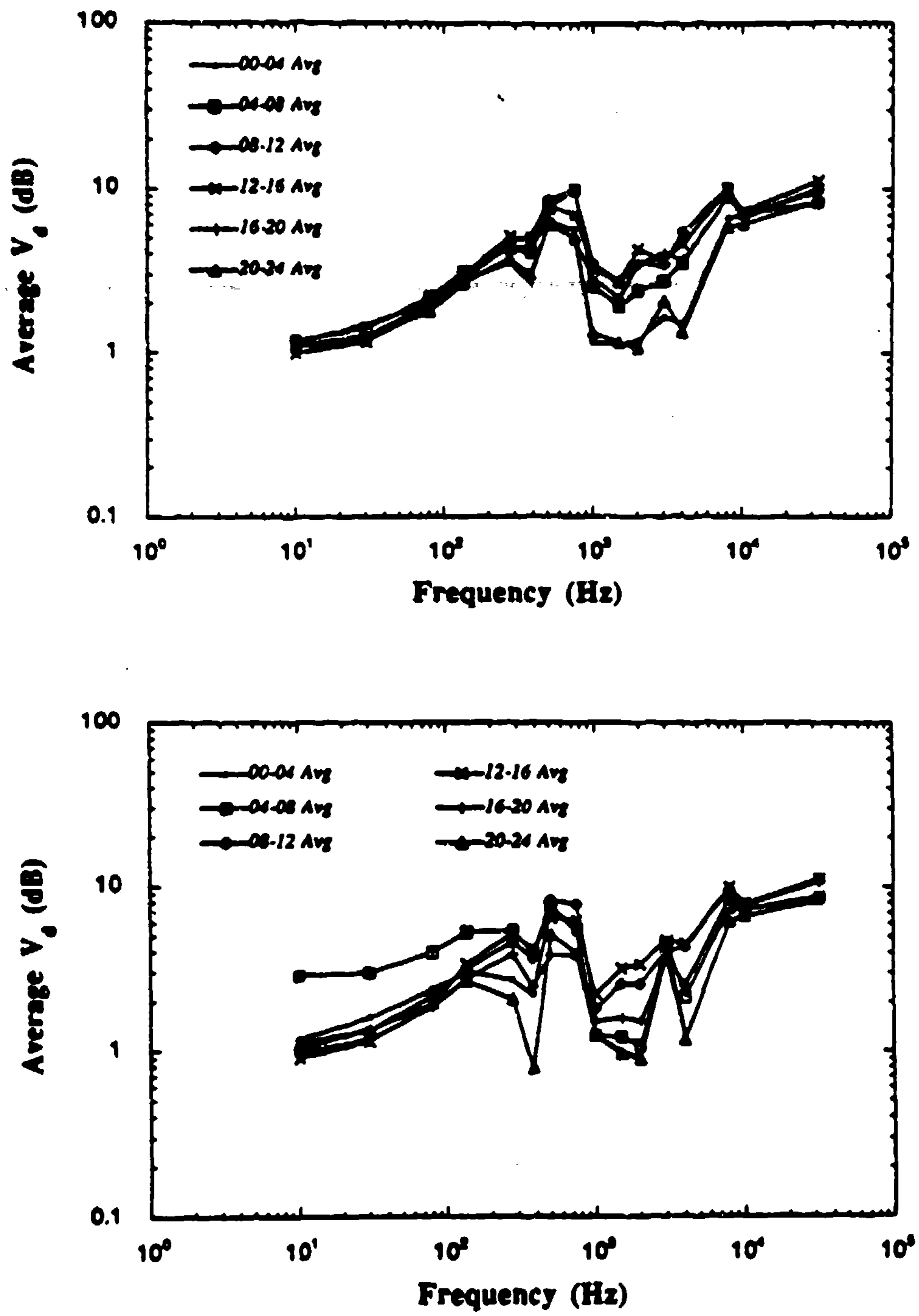
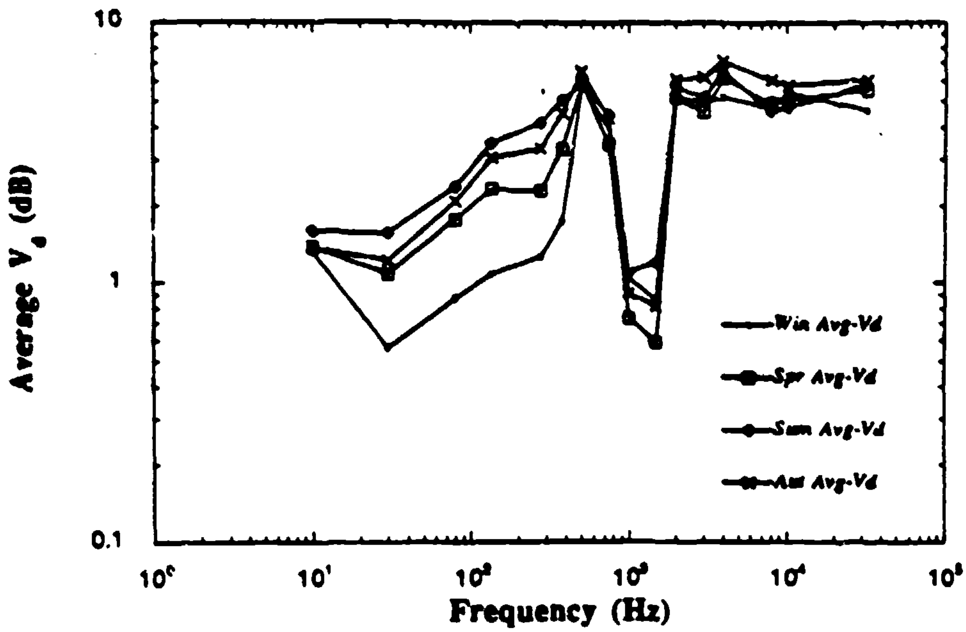



Figure 33. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Arrival Heights, Antarctica, during Summer 1987. The measurements have been averaged at each frequency for the indicated four-hour UT interval. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Arrival Heights, Antarctica, for Autumn 1987.



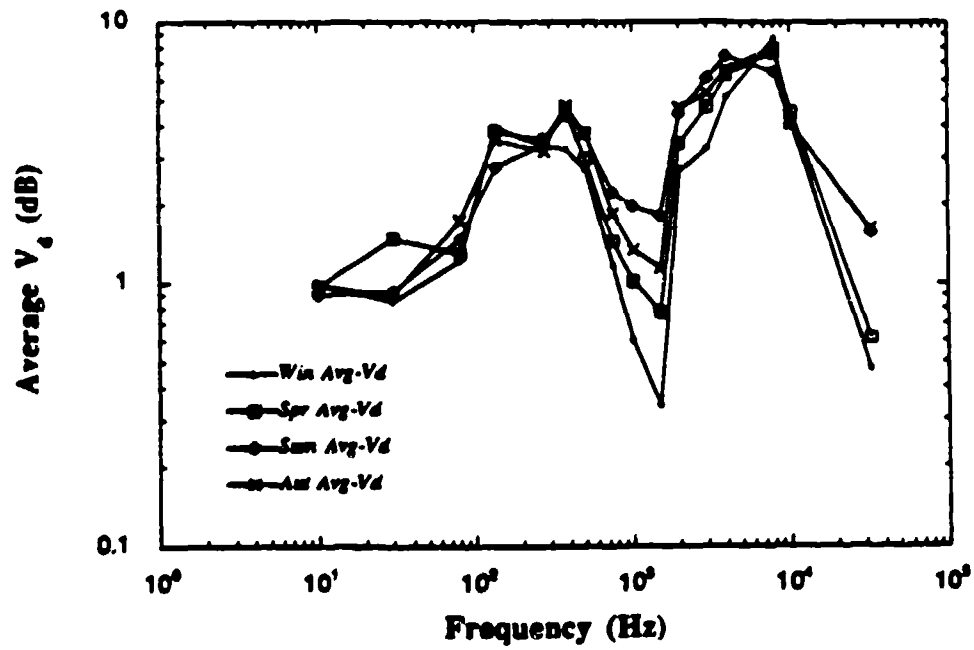




Figure 34. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Kochi, Japan, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Stanford, California, for the 1986–1987 year.

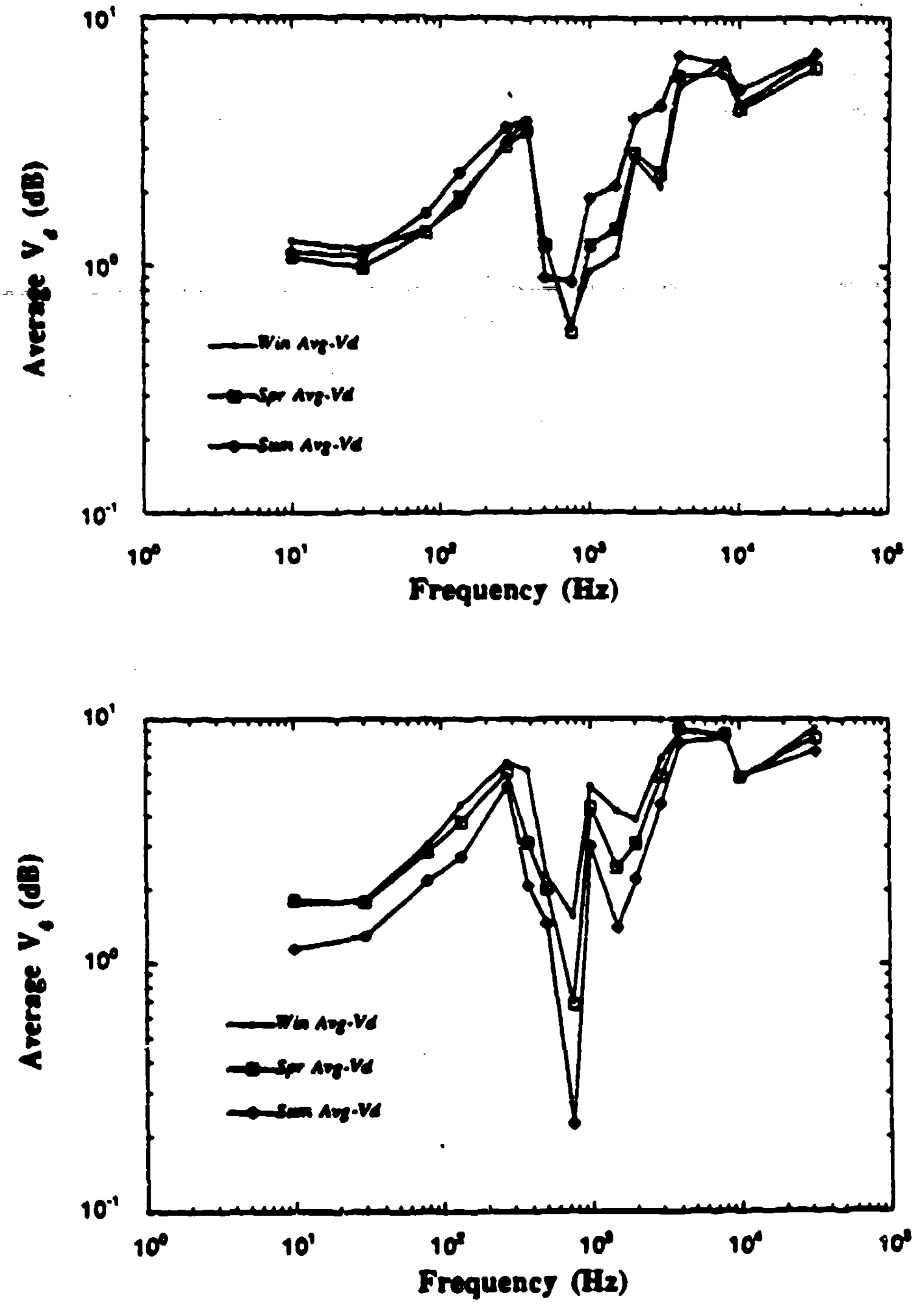
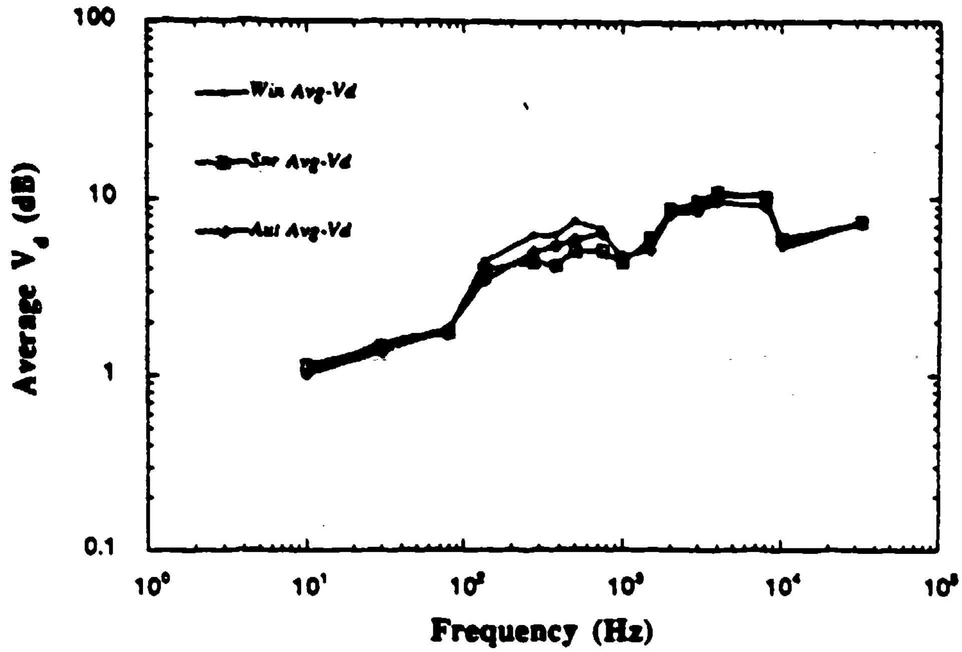



Figure 35. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at L'Aquila, Italy, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Dunedin, New Zealand, for the 1986–1987 year.



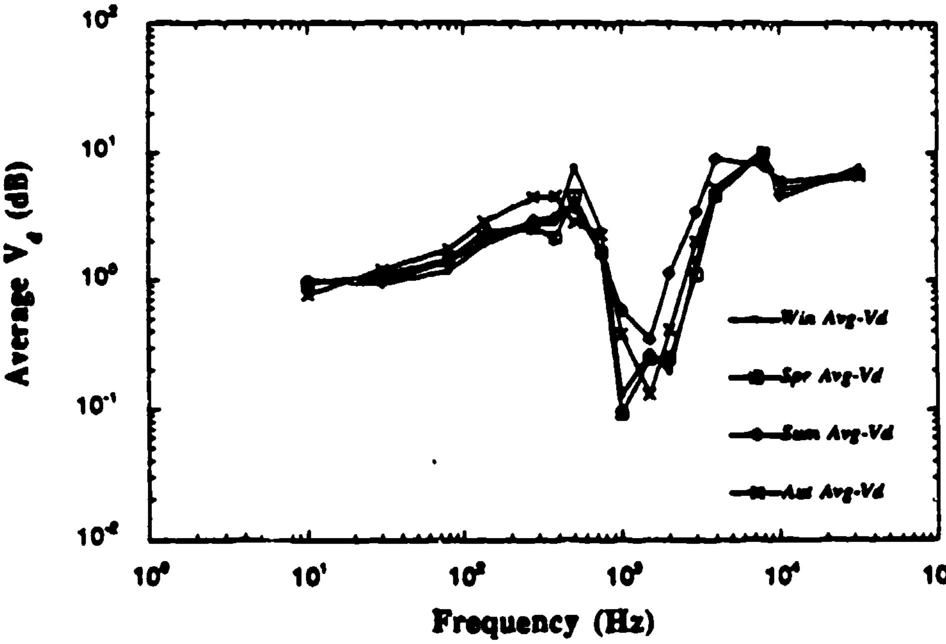




**Figure 36.** (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Søndrestrømfjord, Greenland, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season. (Lower panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Thule, Greenland, for the 1986–1987 year. Measurements made during hours of ionosonde operation have been excluded.

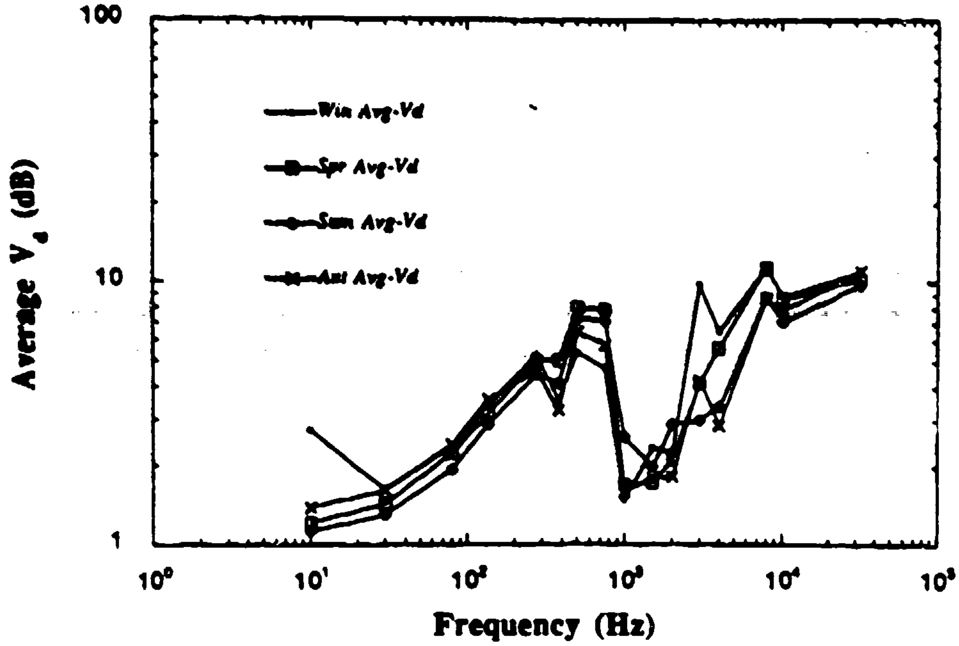



Figure 37. (Upper panel) Variations in the $V_d$ statistic for ELF/VLF noise measured at Arrival Heights, Antarctica, during the 1986–1987 year. The measurements have been averaged at each frequency for the indicated season.

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